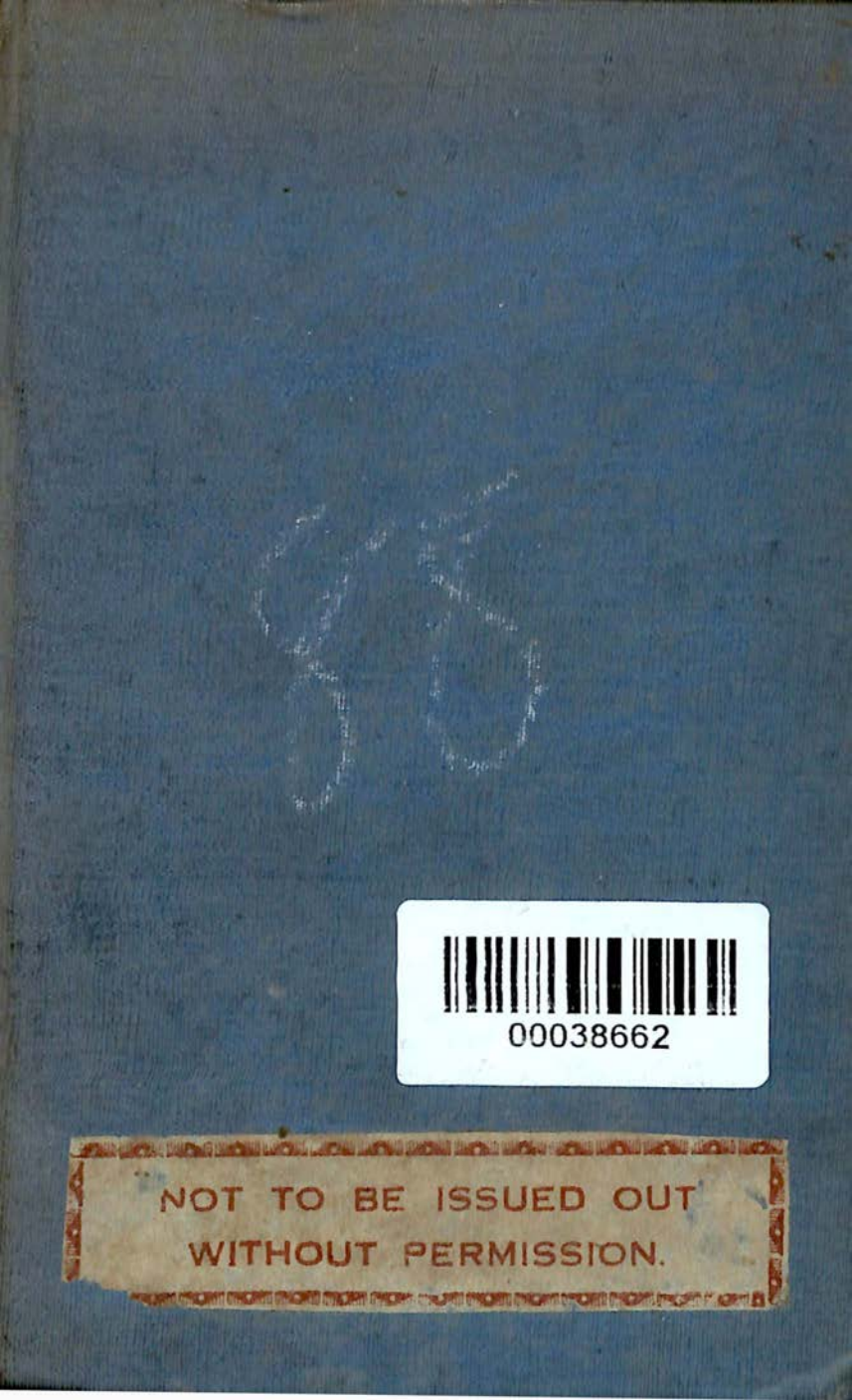

00038662

NOT TO BE ISSUED OUT
WITHOUT PERMISSION.

THE
ASIATIC SOCIETY OF BOMBAY
Town Hall, Bombay.

Digitized with financial assistance from the
Government of Maharashtra
on 05 October, 2018

THE AUTOBIOGRAPHY

OF

THE EARTH

"Oh, that we had eyes to see
The glory that around us lies:
To read the secrets of the Earth,
And know the splendour of the skies."

LEWIS MORRIS (*Songs of Two Worlds*).

THE AUTOBIOGRAPHY

OF

THE EARTH

A POPULAR ACCOUNT OF GEOLOGICAL HISTORY

38662
ac

BY

REV. H. N. HUTCHINSON, B.A., F.G.S.

WITH TWENTY-SEVEN ILLUSTRATIONS

LONDON: EDWARD STANFORD
26 & 27 COCKSPUR STREET, CHARING CROSS, S.W.
1890

[*The right of translation is reserved*]

550
Hut/Aut
38662

TO

PROFESSOR T. G. BONNEY, F.R.S.

THIS LITTLE BOOK IS DEDICATED

IN SINCERE REGARD

BY HIS FRIEND AND FORMER PUPIL

THE AUTHOR.

PREFACE

IN the following pages the writer has attempted to give to the general reader a brief sketch of Historical Geology. Of geological text-books there are many; but his experience goes to show that few people read them, except those who are compelled to do so in order to pass examinations, and that to the general reader such books are dry, uninteresting, or even quite unintelligible.

And yet there is reason to think that the ordinary reader would be glad to know something of this delightful and thoroughly English science. It is delightful because it adds a new interest to the world around us, telling the story of the stones by the road-side, and the rocks we delight to scramble over when enjoying a sea-side holiday, or of the mountains and glens to which we resort for purposes of sport. Again, it is English, or rather British, because its foundations have been mainly laid by the labours of eminent Englishmen and Scotsmen—Wm. Smith, Hugh Miller, Lyell, Hutton, Playfair, and others of

illustrious memory. Many a sportsman or pedestrian, we believe, pauses now and again to examine some curious stone which attracts his attention, or looks at the rock or boulder on which he rests for a mid-day repast, and would like to understand a little of its previous history. But not knowing where to turn for assistance, he remains ignorant of a subject of which even a slight knowledge would greatly add to the pleasure of his rambles over the country.

Hugh Miller's writings, with their graphic descriptions, were at one time largely read; but they are now somewhat behind the times, and there is no living geologist who can entrance his readers as he did.

The scarcity of popular works on Geology at the present time has induced the writer to put together this little book in the hope that it may supply a want.

Its plan is as follows:—*First*, to give in simple language, and in a style which it is hoped will not deter the reader, a brief sketch of the former history of our planet, beginning with its first appearance as a member of the solar system, and passing through all the different geological periods, with their changing scenes and various phases of life, down to the latest period, when man appeared on the scene. *Secondly*, to explain, however briefly, the methods by which the conclusions of geologists have been arrived at, or, in other words, to put the evidence before the

reader so that he may see how those conclusions were formed and judge for himself how far they are reasonable. To do this at all fully in a small book was of course impossible, but it was thought better to attempt brief explanations than to state conclusions which, without reasons, might seem very arbitrary. Such as are given may in some cases be inadequate or incomplete, but at least they will serve to give the reader an insight into the methods of Geology, and may possibly lead some to further study, and especially to personal observation.

Geology cannot be learned from books alone. Observation and a little reflection will help the student far more than reading. Study should be combined with field-work, and in this way only can the subject be mastered.

Almost all sciences bear more or less upon Geology. Chemistry, Physics, Mineralogy contribute their share in the interpretation of the rocks; but those who take up the subject in a practical way and begin to collect fossils will find a knowledge of Natural History of the greatest use. A fish scale, a shell, a bone, or a tooth of some animal will explain themselves to those who are more or less familiar with living forms of life. The would-be geologist should be encouraged to collect and study living forms—the "common objects" of the country or the sea-shore—at the same time that he collects fossils from the rocks, and to place living types side

by side with those of the past which fill his cabinet of treasures.

The labour involved in carrying out the above plan has not been small; but if the writer should succeed in helping others to read for themselves the *Autobiography of the Earth* as written in the rocks he will be amply rewarded for his trouble.

It would be impossible to acknowledge here all the sources from which the writer has drawn; but the leading text-books have been consulted as well as various scientific journals. He would, however, especially acknowledge his indebtedness to the writings of Professors A. Geikie, Nicholson, Green, Seeley, and Mr. Jukes-Browne.

His thanks are due to Messrs. A. & C. Black and to Messrs. Cassell for illustrations lent from their publications. He cannot omit, moreover, to express his best thanks to Miss Buckley (Mrs. Fisher) for permission to use some of the illustrations given in her well-known popular books on science, and for her valuable suggestions while the book was passing through the press.

CONTENTS

CHAP.		PAGE
	INTRODUCTION	1
I.	CLOUD-LAND, OR NEBULAR BEGINNINGS	4
II.	THE KEY TO GEOLOGY	16
III.	AN ARCHAIC ERA	29
IV.	CAMBRIAN SLATES	44
V.	THE SLATES AND ASHES OF SILURIA	60
VI.	THE OLD RED SANDSTONE	74
VII.	THE MOUNTAIN LIMESTONE	91
VIII.	FORESTS OF THE COAL-PERIOD	106
IX.	A GREAT INTERVAL	126
X.	THE CHESHIRE SANDSTONES	142
XI.	NEW PHASES OF LIFE	159
XII.	BATH OOLITES	177
XIII.	AN AGE OF REPTILES	199
XIV.	THE CHALK DOWNS	217
XV.	THE NEW ERA	237
XVI.	THE ICE-AGE AND ADVENT OF MAN	252

LIST OF ILLUSTRATIONS

FIG.		PAGE
1.	SECTION ILLUSTRATING UNCONFORMITY	45
2.	SECTION ACROSS CAMBRIAN AND PART OF THE LOWER SILURIAN ROCKS OF MERIONETHSHIRE	51
3.	A CAMBRIAN TRILOBITE (*Paradoxides*)	57
4.	A LIVING CORAL	71
5.	CEPHALASPIS, AN OLD RED SANDSTONE FISH	88
6.	OLD RED SANDSTONE FISHES; *a.* PTERICHTHYS, *b.* COCCOSTEUS	89
7.	PIECE OF LIMESTONE SHOWING STEMS AND PLATES OF ENCRINITES	93
8.	COAL UNDER THE MICROSCOPE, SHOWING SECTIONS OF STEMS OF FERNS, CALAMITES, ETC.	113
9.	A FOREST OF THE COAL-PERIOD	117
10.	DIAGRAM SHOWING THE ORIGIN OF THE BASIN-SHAPED FORM OF MANY COAL-FIELDS	138
11.	THE GEOLOGICAL CLOCK, SHOWING THE ORDER OF SUCCESSION OF THE DIFFERENT PERIODS, AND FIRST APPEARANCES OF VARIOUS TYPES OF LIFE	154
12.	SKELETON OF PLESIOSAURUS FROM THE LIAS	166

FIG. PAGE

13. SKELETON OF A GIGANTIC DINOSAUR (*Iguanodon*) FROM WEALDEN STRATA 171
14. THE FISH-LIZARD (*Ichthyosaurus*) 206
15. REMAINS OF ARCHÆOPTERYX FROM THE SOLENHOFEN SLATE 215
16. SECTION ACROSS THE WEALD 218
17. MICROSCOPIC FLINT SHELLS (*Polycistinæ*) 225
18. VENUS'S FLOWER-BASKET—A SILICEOUS SPONGE . . . 226
19. CRETACEOUS CEPHALOPODS 233
20. SECTION ACROSS ISLE OF WIGHT 240
21. GLACIER OF THE PASS OF LLANBERIS (RESTORED). SNOWDON IN THE DISTANCE 270
22. MODERN FLINT IMPLEMENT ATTACHED TO A WOODEN HANDLE, TO BE USED AS A HATCHET 274
23. THE GREAT IRISH ELK (*Megaceros Hibernicus*) . . . 275
24. SKELETON OF DIPROTODON, A GIGANTIC EXTINCT MARSUPIAL 277
25. *Dinornis elephantopus* (SKELETON), AND LEG-BONE OF *D. giganteus* 279
26. MEGATHERIUM, A COLOSSAL SLOTH-LIKE EDENTATE FROM PLEISTOCENE DEPOSITS OF SOUTH AMERICA . . 280
27. EXTINCT GIGANTIC ARMADILLO (*Glyptodon clavipes*) . 282

THE AUTOBIOGRAPHY
OF
THE EARTH

INTRODUCTION

And Nature, the old nurse, took the child upon her knee,
Saying: "Here is a story-book thy Father has written for thee."
"Come wander away with me," she said, "into regions yet untrod;
And read what is still unread in the manuscripts of God."

LONGFELLOW'S *Ode to Agassiz.*

THE story which we are about to read has not been written by man, but, as the poet tells us, by the Creator himself; and therefore we can trust absolutely the truthfulness of the record. It is a plain unvarnished account, in which man has no hand—not a complete account, and there are at present many gaps in it, but these may be filled up in time as we see more of the rocks of other countries.

The "imperfection of the record" on which Darwin lays such stress is not to be denied, but for all that, we shall probably find that enough is left to give us a very good general idea of each important period in the past history of the Earth. The beauty of the record is its truthfulness. We may err in our interpretation of some passages here and there, but

that is our fault. The symbols and the strata, or pages, on which they are written are absolutely free from interpolations or misrepresentations. Human history we do not find to be absolutely impartial and truthful. But here we shall find nothing extenuated, nought set down in malice.

The Earth is its own Biographer, and keeps its diary with the impartiality of a recording machine. Now the earlier chapters of the record are not so easy to read, nor are they so complete, as the later ones. This is only what we might expect, and what we find to be the case with the histories of nations. Who knows what the Egyptians were doing before the first king, Mena? Before then they say the gods reigned in Egypt, which only means that no record is left of their early days.

But the history of the earth before the geological record began is not so much out of our reach. There is a record, but it is not strictly a geological record. This part of the story belongs rather to the chemist and the astronomer than to the geologist. Still all the sciences overlap one another, and it would be a good thing if they were a little more "cross fertilised" than they are. We will therefore, in order to make the story complete, try and read a little of this first chapter, which contains an account of the birth and early growth of our planet, although it is often in a different dialect of the language we shall come to later on, and one not quite so easily read. And here we may point out that the geological record proper did not begin until the earth was cool enough to allow of a watery envelope settling down on its surface,

just as dew from the atmosphere settles on the cold earth at night, and so forming the primeval ocean, which probably covered the whole surface, so that, in the words of the poet,

"A shoreless ocean tumbled round the globe."

Land and water are the paper and ink with which the geological record was written. In going back to periods anterior to those of the geologist we find ourselves in company with the astronomer and physicist.

But let us see what they have to tell us. If they speak with less certainty than geologists we shall be compensated, I think, by the greater delight in making out even a few of the queer symbols to be found in this first chapter of Earth's autobiography, just as the etymologist finds great interest in the tracing, by means of words, the history of nations that either could not write, or have left no written record to tell us of their doings. Well, perhaps Mother Earth was only learning to write in these very early ages, and if her caligraphy is a little obscure I am sure we can forgive her, especially as it seems she was but scantily provided with writing materials. One more excuse I think we ought to make for her; the documents we are about to deal with are so very ancient (hundreds of millions of years old) that we ought not to be surprised if we find them the worse for wear, and that in some cases they have had a later record written over them, like the palimpsests which give so much trouble to students of the New Testament to read.

CHAPTER I

CLOUD-LAND, OR NEBULAR BEGINNINGS

"Speak to the Earth and it shall teach thee."—JOB. xii. 8.

WHAT we have to do in order to read this our first chapter is to collect evidence from all quarters, just as a jury has to do in order to find out what the prisoner was doing at a certain time. We want "circumstantial evidence," and must keep our eyes open for it. But, as one thing leads to another, so we find that the early history of our planet cannot be considered apart from that of the solar system, of which it is only a member. It will therefore be our endeavour to give a very brief sketch of the growth and development of that system as far as it can be made out at present.

"This world was once a fluid haze of light."

These are the words in which our Poet Laureate's Princess commences her sketch of the origin of the world (see p. 9). They express in a poetic form what astronomers have concluded from a study of the facts. Let us see what these facts are, re-

membering that to us they are but symbols—circles, ellipses, etc., primeval hieroglyphics, in which sun, earth, planets and satellites began to write their story—and that even the wisest astronomers and physicists are but children, trying with more or less success to spell out their meaning. In the first place, the very fact that our planet is only one member of a group of bodies known as the solar system would lead us to inquire how far each member of that family may have had a similar origin, and whether the big hot body in the centre may not be the *paterfamilias*, the father of the family. (2) Recent researches in solar chemistry and physics have shown that the sun contains a large number of the chemical elements known to us on the earth. It would take too long to describe the methods by which this and other results have been obtained. Sufficient to say that although for ages upon ages Phœbus has been sending to listless mortals a series of heliographic messages, telling of his chemical and physical constitution, yet until the invention of the spectroscope man was no more able to read his flash signals than the Zulus could read General Wood's signals from Eckowe. But now that we know, partly at least, his code, we begin to have some idea of what the sun is, and we find his message to be somewhat of this kind :—

"I am your parent, you were once bound up with me, but by centrifugal force (due to rotation) I threw you off as a ring. You then rolled up into a ball as your brothers and sisters have done. But my son Saturn still has a ring, or what looks

like a ring, round him, to show you how my children follow my example and throw off rings, which in time become satellites. You were once as hot as I am, but being so much smaller you cooled more rapidly. You once had a coronal atmosphere consisting mainly of hydrogen gas, as I have, and beneath that a chromosphere, with vapours of incandescent hydrogen, calcium, and magnesium, with successive denser layers below containing iron, manganese, and other metals with which you are well acquainted. Even now you cannot help seeing that your own earth has its materials arranged in layers according to their density, first an envelope of thin air, then one of water, then one of rocks two or three times as heavy as water, and below that heavier materials, probably metals, because Cavendish who weighed your planet for you found it was five times as heavy as water. Nor will you have forgotten Sir Humphry Davy's theory of a metallic interior."

Now, besides this message which Kant, Laplace, Herschel, Lockyer, and others have spelt out for us, comes a whisper of confirmation from the stars, caught by the attentive ear of Mr. Huggins. On turning his spectroscope beyond the sun to stars and nebulæ, he finds the hydrogen lines very prominent in certain spectra, and conceives that they may be glowing masses of that element. Among the fixed stars, spectra have been recognised pointing to a structure similar to our sun, namely an incandescent nucleus, surrounded by an atmosphere of glowing vapour. Mr. Lockyer thinks that the stars with the simplest spectra are the hottest, and that as they cool their

materials become more and more complex, combining into what we call "elements" (but which may after all be only combinations of one elementary kind of matter). Our sun would then be cooler than Sirius and some other fixed stars, because its light in passing through the spectroscope betrays the presence of metals, such as magnesium, sodium, calcium, and iron, whereas our own earth being so much cooler contains substances such as carbon and oxygen known as metalloids, and compounds such as chloride of sodium and carbonate of lime, which certainly could not have been present during the earlier and hotter stages. (3) The telescope has, in the hands of Herschel and others, done very much to throw light upon the embryology of stars and the groups of planets probably revolving round them as we revolve round the sun, so that although no man saw the evolution of the solar system, yet we can get a very fair idea of it, because we have around us systems in various stages of growth, and perhaps decay, just as we have only to go into a forest to see every stage of the growth of forest trees, from the little seed to the prostrate trunk which the woodcutters have felled, although no one lives long enough to watch the life-history of one big tree. The idea of the nebular theory is that a nebulous mass [1] contracts, and in so doing gives out heat; a movement of rotation begins, and as this causes

[1] Nebulæ were formerly considered to be gaseous, but the recent researches of Lockyer seem to show that both comets and nebulæ are simply swarms of meteorites. These by clashing together may generate enough heat to vaporise a portion of the mass. Thus suns and stars would all take their origin from meteorites.

centrifugal force the outer portions, which will naturally be the lighter, fly off in rings and eventually form planets, satellites, and meteoric rings.

The evidence given so far may perhaps seem too slender a foundation to build such a big theory upon; we will therefore give some further evidences (continuing our numbers) in order that the reader may judge whether the symbols thus given can be interpreted as part of the same story which has just been briefly sketched.

Number (4) is this: that the temperature of the earth increases as we go downwards at the rate of about 1° Fahr. for every 50 feet, so that we may readily believe that some parts of the interior may be as hot as molten iron or even molten platinum. But that by no means implies a liquid interior, as geologists formerly thought, because we know that at great depths rocks must be subjected to the enormous pressure of the miles of superincumbent rocks which may keep them solid in spite of a high temperature. The fact of molten lava flowing from volcanoes in no way militates against this, because that probably comes from no great depth below the surface. The mass of granite now known as Dartmoor was once molten, and doubtless supplied lava to old volcanoes on a surface that has been quite worn away by subsequent denudation. (5) The revolution of eleven planets in the same direction round the sun. (6) Their revolution round the sun in nearly the same plane, that in which our earth moves round the sun, and known as the ecliptic, so called because eclipses can only take place when the

moon is also in that plane. (7) The revolution of the planets and satellites in orbits nearly circular. (8) The flattened figure of the planets, especially those endowed with a rapid rotation. Thus our own earth is 26 miles shorter from pole to pole than it is the other way across. This points strongly to a former semi-fluid condition, and in fact the shape of the earth is just that particular shape which a soft rotating body must assume: the lump of heated glass at the end of the glass-blower's rod becomes very flattened at its poles as the rod is spun round and round on its axis. (9) The phenomena of Saturn's ring and the asteroids between Mars and Jupiter. (10) The much greater density of the planets near the sun than that of those farther away, viz. Jupiter, Saturn, Uranus, and Neptune, which are about as light as cork. This also is a very easy symbol to interpret, for the lighter portions of the original rotating mass would naturally be the outer portions, and these would at last break away in rings. (11) The lightness of the moon compared with the earth—same thing on a smaller scale.

We would now ask the reader if these facts do not all seem to point in the direction of the nebular theory; if these cosmic symbols do not seem to tell the same story, and confirm the idea that

> "This world was once a fluid haze of light,
> Till towards the centre set the starry tides
> And eddied into suns, that wheeling
> Cast the planets."

If not, would the reader try and see whether any other story can be spelt out from these cosmoglyphics?

We must here leave this interesting subject and proceed to read the next chapter of the story of the Earth, written by herself. Our reading is doubtless a rather incomplete and stumbling one at present, and we trust that future generations will read it much better. But for all that it must surely be a true source of pleasure to know even this much of a subject which would seem at first to be quite beyond the ken of mortal man. Having taken a bird's-eye view of our earth and the system to which it belongs, and having, in imagination, watched its development from a meteoric cloud or swarm, it is now time to leave our standpoint in space and descend a little nearer to the earth, and presently to devote ourselves to the examination of the rocks forming its surface, or so-called "crust," in order to endeavour to read the record they contain.

It is hardly perhaps necessary to say that the rocks we are about to consider are all "stratified," or laid down in layers of varying thickness, and in some cases cover very large areas of the earth's surface. They may be best compared to blankets and sheets placed on a mattress, the latter representing the old primeval surface of the earth, probably composed of some igneous rock like granite, on which consolidated surface the ocean was gradually collected as the process of cooling progressed. The first stratified rocks must have been largely formed by the denudation of this surface. That a very long time elapsed between this era and the first existence of our planet as a separate body cannot be denied; but it is a period about which

very little is known. The geological record not having begun, it is only possible to infer by speculation and reasoning from a few known facts that consolidation, as the result of cooling, was taking place, and that thereby the globe was becoming more fitted for the abode of living organisms and for those great cycles of change with which we are now familiar, such as the circulation of water, the wear and tear of the land, and the transportation of its débris by rivers and glaciers into seas and lakes, where it is slowly built up into new strata destined in their turn to be lifted up and to form the continents of the future. In a book such as this it will not be necessary to consider the opinions of geologists and physicists about this long period of the earth's history further than to say that certain interesting astronomical discoveries regarding the position and motions of the earth and moon at that time have recently been made by Professor George Darwin (the result of his profound mathematical investigations into the subject of the tides), and to give a brief account of the results.

He finds that at one time the earth and the moon were one mass, that owing partly to tides caused therein by the sun's attraction, and partly by the centrifugal force due to its rotation, a separation took place and the moon was thrown off. The birth of the moon, thus for the first time established by mathematical reasoning, makes a definite and interesting epoch in cosmic history. The results are to be found in a series of papers in the *Philosophical Transactions* for 1879, Parts I. and II. But papers such as these

are not intelligible to the ordinary reader; it is well, therefore, when an interpreter comes between learned scientific men and the general public who is willing to undertake the task of giving a simple and popular account of their work and the methods of reasoning employed. Such an interpreter is to be found in Professor Ball of Dublin, who in an interesting lecture delivered at the Midland Institute, Birmingham, gave his audience a graphic and eloquent *resumé* of the new and interesting results ("A Glimpse through the Corridors of Time," reported in *Nature*, vol. xxv. pp. 79-103). He thus describes the state of things immediately following the birth of our satellite:—

"In those ancient times I see our earth to be a noble globe, as it is at present, yet it is not partly covered with oceans and partly clothed with verdure; the primeval earth seems rather a fiery and half molten mass, where no organic life can dwell. Instead of the atmosphere which we now have I see a dense mass of vapours, in which perhaps all the oceans of the earth are suspended as clouds; I see that the sun still rises and sets to give the succession of day and night, but the day and night together only amount to three hours instead of twenty-four. Almost touching the chaotic mass of the earth is another much smaller and equally chaotic body. Around the earth I see this small body rapidly rotating; the two revolve together as if they were bound by invisible bands. This smaller body is the moon." The moon has been receding ever since, until now its distance is about 240,000

miles. At the same time its rate of rotation on its axis has been steadily diminishing (on account of tides caused by the earth), so that now it takes twenty-seven days to rotate once on its axis; but as the earth caused tides in the moon, so the moon has been, and still is, causing tides on the earth, both in its watery envelope and also in its outer crust. Professor Ball concludes that such tides must have been much more powerful than those which we see now. This causes friction, and thus acts like a brake on a wheel, so that now our day is 23 hours 56 minutes and 4 seconds long instead of 3 hours only. This tidal retardation, it is calculated, will continue until the day is 1400 hours long! At this point Professor Ball humorously asks his Birmingham audience "Where then will be the nine hours movement?" This state of things, 700 hours of day and 700 hours of night, will, he says, endure for a very long time, but it will not be final. Another authority tells us that a time will come when our earth will cease to rotate altogether, the result of which will be six months of daylight and six months of darkness!

We have introduced the above results here, not only on account of their profound interest, but because they have a direct and important bearing upon the subject of this book. The geologist naturally asks whether the great tides of ancient times, at least two or three times as great as modern tides, and this much more rapid rotation of the earth, were taking place during any portion of that period of the earth's history which is his special province. *If* this can be

proved—and it is by no means proved yet—then the geologist will be obliged to conceive of the geological forces which wear away old rocks, and build up new ones, operating with more celerity than he is at present inclined to admit. For if at any time since first the ocean was formed, and all the work of "denudation" begun, the rise and fall of the tide was two or three times what it is now, or, owing to more rapid rotation of the earth, "trade winds" were more powerful, and on account of the more rapid alternation of day and night, winds and storms were more violent, leading to more active ocean currents, then the geologist would justly conclude that under these more active meteorological and other conditions, a hundred feet of strata would not require anything like such a long period of time for their accumulation as they seem to require at present.

In this way a great controversy has risen up between geologists on the one hand, who take it as a fundamental doctrine of their science that physical changes on the earth have been taking place at a tolerably uniform rate, and very little, if any, faster than their present rate, and physicists and astronomers on the other, who tell the former that their demands for geological time are far too great, that at *most* they must be satisfied with 500,000,000 of years, and that probably 100,000,000 of years ought to be quite sufficient to build up the great pile of stratified rocks whose record they are engaged in interpreting, and to allow also for all those great changes in the vegetable and animal world which are plainly recorded by an abundance of evidence from the fossils

contained therein. But, as the whole question depends on the "if" already stated, it may be hoped that the geologists and physicists will not quarrel seriously, and that the former may be allowed to say with Touchstone, "Your 'if' is the only peacemaker. Much virtue in 'if.'"

CHAPTER II

THE KEY TO GEOLOGY

"'Was the world not made at once then?' said Felix.
'Hardly,' answered Jarno. 'Good bread needs baking.'"
Wilhelm Meister's Travels.

THE object of this little book is not only to give an outline of geological history, but also to endeavour to explain, however briefly, the principles and methods by which that history has been read. It will not be sufficient to give a sketch of what was taking place in this part of the world during each geological period, so far as that may be possible, and it will be advisable to show the reader *how* the story is read from rocks and fossils. Any one who will take the trouble to read even a part of some popular text-book on physical geology and learn how rocks are formed, how continents are worn down by "denudation," and get some idea of the laws which govern the growth of plants and animals, their modification and distribution in time and space, will find himself amply rewarded for his trouble when he perceives that he has to a large extent mastered the

grammar of a language written in the stones of the house he dwells in, the walls he passes by every day, the public buildings of his town or city, the cliffs at his favourite sea-side resort, or the glens where he may wander with gun or rod in search of sport.

But to give a complete account of the principal changes now taking place on the earth's surface would expand this book into a treatise on geology; for such we must refer our readers to some of the admirable text-books on physical geography which have been published of late years, such as Huxley's *Physiography*, Geikie's *Elementary Lessons in Physical Geography*, or Jukes's *School Manual of Geology*. No one can read the language of the geological record unless he first acquires some knowledge of the grammar of that language. Now the grammar of geology is physical geography; or, in other words, it is impossible rightly to interpret the past without some knowledge of the present. A cliff section is as unreadable to one who has no idea of the way in which shales, sandstones, or limestones have been formed as the hieroglyphics on an Egyptian temple were to the Greeks and Romans, who were unacquainted with the *meaning* of the symbols employed in that system of picture-writing. But when we once have gained even a general idea of the processes by which stratified rocks have been formed, and in some places vegetable or animal organisms buried up and preserved therein, we find it by no means difficult to decipher Earth's picture-writing and to read in outline the record of the commoner rocks around us.

An illustration will help to make this clear. Suppose an intelligent but untaught child from a slum were asked how a loaf of bread was made, he could not tell. He would say it came from the baker's shop, but that would probably be the limit of the child's knowledge of the matter: sufficient for him if his parents can manage to give him a daily supply. Now the best way to teach the lad the history of the loaf would be to let him see each stage in the process; to take him to the cornfields in harvest time that he might see the labourers carrying the ripe corn, then to the miller's that he might see it ground into flour, and lastly to the baker's shop, where he would see the baker at work, first kneading it up with water into dough and then putting it into his oven to bake it into bread; only in this way would it be possible for him to know and understand the history of a loaf. He would then perceive that every loaf of bread had been thus treated, and was in itself a sure testimony to the cycle of operations above mentioned; for "good bread needs baking." So it is in geology. One could no more reasonably expect a person to tell you the history of a lump of sandstone or a block of slate who has neither been taught, nor observed for himself, the manner in which "rain and rivers" wear down the rocks on the land and bring them to the sea that they may be slowly deposited to form new rocks, than we could expect the slum boy to tell you the history of the loaf of bread. Now the principle thus briefly laid down—that we must interpret the past by the light of the present, and that we can only

interpret the record contained in the stratified rocks by first acquiring a knowledge, by direct observation and self-instruction if possible, of the chief operations now taking place on the earth's surface —is the fundamental doctrine of geology.

Such knowledge is the key which unlocks the door of our hidden treasure. This principle is called by geologists the doctrine of "uniformity." It arose from the teaching of the celebrated Scotchman, Hutton, the founder of the new teaching which has done so much to advance the science, and the great opposer of the old teaching known as "Catastrophism." The old teachers up to the end of the last century (and a good deal later unfortunately) explained many geological phenomena by the aid of a powerful imagination. They saw in the upheaval of mountain chains, in the marked differences between the fossils of one group of rocks and that succeeding it, and other well known facts, the results of great and violent revolutions or catastrophes; hence they did not hesitate to believe in enormous and destructive floods, in stupendous earthquake waves, in violent upheavals and crushing of the rocks on the earth's surface, and in other things which, we hope, are now for ever banished from the minds of geologists. For instance, a river gorge was considered to be a chasm formed by some violent shock; it did not occur to them that a river could slowly carve out in the lapse of ages a deep and steep valley for itself. Again, a volcano was thought to be the result of a sudden upheaval, whereas we know that all volcanoes have been slowly piled up by ejections of ashes,

lava, etc. It is not difficult to trace the cause of this error. Had they only been a little more patient and not jumped to conclusions on the great problems of their science, they would have reasoned thus with themselves: "Here is a deep river gorge" [for example]; "let us see if there is any evidence that such things are now being formed. It does not seem very likely at first sight, still we ought to proceed carefully; such things clearly have been formed in the past, may they not be in process of forming somewhere or other in the present? Let us study Nature herself, let us examine her methods of working before we invent theories out of our own brains to account for the things she has done."

Had they thus restrained their eager imaginations, and humbled themselves to the drudgery and discipline of a searching inquiry into the operations now taking place, they would neither have brought forward such ridiculous explanations, nor hindered the science to which their energies were devoted. But we may say in this case too, "The wish was father to the thought"; for the chief cause of their error was the assumption that the world was only a few thousand years old, and therefore it is obvious that it was necessary to assign to geological operations a very great speed. Everything had to be hurried up. In the very short space of time allowed for geological history a vast series of stratified rocks had to be deposited, great mountain chains elevated, volcanoes formed, a great deal of granite, basalt, and schist somehow made, great changes in the vegetable and animal world to take place. How else could they

get out of the dilemma? Even if they did, they did not perceive their position to be that of a person "between two stools," on the one hand they dare not entertain for a moment the idea that the current teaching about the world's age might be insufficient; on the other hand they failed to realise that stupendous results may be obtained by causes seemingly very insignificant, if only plenty of time be allowed. But the teaching of Hutton was in advance of his time. Not until this principle of "uniformity" was worked out by Sir Charles Lyell and put forward in that great book, *The Principles of Geology*, did the new teaching find favour and spread. Since its adoption geology has made enormous strides. It has produced more results than the work and thought of previous geologists ever since the time of Herodotus—in fact it was nothing less than a reformation. Hutton was its Morning Star, its Wycliffe; Lyell its Luther; but it was a very quiet and peaceable reformation. What better testimony to the soundness of modern geological teaching could be desired? It may safely be judged by its fruits. At the same time it would be unwise to push the theory of uniformity to its extreme limits, and to assume that ever since geological history began "geological agents" have been operating at an absolutely uniform rate; to lay it down, for instance, as an axiom that the rainfall in ALL past ages was just the same in intensity and amount as we find it to be at the present time, or that the winds and storms were never more violent than they are at present, or that tides have always been ebbing and flowing

with no more power nor within wider limits than they may do at present. This would be to ride our hobby to death. In the last case we have seen that a greater power was possibly given to the tides within geological times. Nor is the idea to be scouted that perhaps in the earliest periods the sun's heat may have been sensibly greater; for that body is believed to be cooling, and therefore, unless the loss is made good in some way, it must have been sensibly hotter then than now. This would tend to affect the climates of those periods. These things should be borne in mind. At the same time there seems to be no evidence at present of any greater intensity in the action of geological agents.

Geology may be said to be the natural history and physical geography of the past. In this it differs materially from other sciences, being rather the application of many sciences to one object, namely the finding out the past history of the earth. Hence there is no subject so wide in its range. It is therefore necessary to call in the aid of other sciences. The chemist tells us how certain minerals we meet with have been formed. The physicist gives us valuable information for the study of such phenomena as winds and ocean currents, or earthquakes and volcanoes. The anatomist tells us the meaning of the structures we meet with in fossilised remains of animals. The naturalist tells us about the habits of animals and plants, the laws governing their distribution both on land and in the sea. All contributions towards this great object are thankfully received. It is clear therefore that no one man can

master the whole of geology. Still it is within the reach of any student to gain a good general idea of the subject, and to learn the results obtained in each department.

We propose now to give a brief summary of the work of geological agents, and to state in a few words what is the nature of the operations they perform. This plan will avoid repetition, and enable us hereafter to dwell more fully on the work of certain geological agents when we come to the consideration of those rocks wherein their work is made manifest.

It is not easy to define a geological agent; but whatever produces, or tends to produce, an important change in the surface or structure of the earth's crust may be reckoned as one of these agents—whether it be a river, or a glacier, or a volcano, or some kind of living organism, such as a coral or a plant. Thus a river brings down mud and sand from the district through which it runs into the sea, where such materials will, on sinking to rest, build up new rocks or "formations." Hence a river is an important geological agent. We will now draw up a list of such agents, arranging them under the four heads—AIR, WATER, LIVING MATTER, HEAT.

All we can do here is to indicate very briefly the kind of work done by each agent.

I. AIR.	The Atmosphere.
II. WATER.	Rain and Rivers. Glaciers and Icebergs. The Sea.

III.	LIVING MATTER.	Man.
		Plants and Animals.
IV.	HEAT.	Heat of the earth in connection with earthquakes and volcanoes; also with the alterations taking place in rocks. Earth movements due to the cooling of the earth.

Light, electricity, and gravitation all have their share in the work of these agents. Thus most living things require light; electric currents run over the earth; and gravitation makes rivers flow, rain descend from the clouds, and mud sink in the sea.

I. *The Atmosphere* plays its part in geological operations. Its corroding power, backed by rain and wind, helps to decay and disintegrate those rocks which are exposed to its influence. Rain completes the work thus begun. Winds blow dust, sand, and volcanic ashes over large tracts of the earth, in fact over the whole of it. It is only of late years that geologists have discovered that fine volcanic dust is carried over the whole of the earth's surface, and plays a very important part in the deep-sea deposits. On deserts and nearly rainless regions blown sand will wear away the hardest rocks by beating against them. Some sandstone formations appear to have been piled up by winds.

Winds cause ocean currents, waves, and storms. The great denuding power of the sea is largly due to the atmosphere. Some parts of the English coast are being rapidly washed away. Plants and animals have their distribution considerably affected by winds and ocean currents. Again, whether

living in water or on land, animals live on the oxygen supplied from the atmosphere; and land plants absorb carbonic acid from the same source.

II. *Water.*—Rain acts in two ways: (1) chemically by dissolving certain substances; such as lime, out of the rocks, and (2) mechanically by wearing down their surfaces as it flows over them. Any old building—a ruined castle or cathedral, for instance—shows a "weathered" surface resulting from the action of rain and wind. In sandstone structures the details of carving are often lost; and on old tombstones the lettering can hardly be deciphered. Springs are due to rain-water collecting in rocks and rising to the surface. Rivers are fed by rain and springs. A river is a very powerful geological agent. In the hardest rocks rivers gradually carve out a valley or a gorge. This is accomplished partly by chemically dissolving certain mineral substances, but chiefly by mechanical erosion, the stones, sand, and mud wearing away the bed of a stream as they run and tumble over it. The finest examples of river action are the famous Cañons of Colorado, which in some places are gorges five or even six thousand feet deep, with vertical sides. But, as already pointed out, rivers have a *con*structive action quite as important as their *de*structive action. By bringing down their burden of sediment into lakes, estuaries, and seas, they build up great piles of rock, and "sow the dust of continents to be."

Glaciers are rivers of ice fed by the "eternal snows" of high mountain ranges such as the Alps. They wear out their own valleys as rivers do; they

transport mud, sand, and stones to great distances, in some cases sending them sealed up in icebergs to float far out to sea, and on melting deposit their burdens on the sea floor. Off the coast of Newfoundland northern icebergs are depositing a great mass of "glacial drift."

The *sea*, as already indicated, is a great denuding agent; but its work is more *con*structive than *de*structive. It is the workshop where nearly all the stratified rocks have been accumulated and ranged in layers or "strata." The rivers and ocean currents continually bring in fresh supplies of debris, even for hundreds of miles. But far out at sea, where no sediment can reach, certain marine organisms such as foraminifera, corals, shells, etc., build up in the course of ages great deposits of limestone. In the deepest and most inaccessible portions it seems that nothing but volcanic and meteoric dust accumulates. We shall refer more fully to these interesting processes in some of our later chapters.

III. *Living Matter.—Man*, compared with the lower animals, produces but little effect as a geological agent. Still the human race has considerably modified the distribution of plants by cutting down forests, and by cultivating certain plants to supply food. So with animals; certain useful species have been cultivated and enormously increased at the expense of others which prove useless or harmful. Changes on the earth's surface have been wrought by building towns, cutting canals, and draining and cultivating large tracts of land.

But *plants and animals* have had, and still have,

far more influence geologically. Coal-seams are made up of vegetable remains of former periods. Forests have an important influence on climate, and on animal as well as plant life. In the comparatively unknown world of the ocean marine plants doubtless have important functions.

Marine animals accomplish a vast amount of geological constructive work. Of the parts played in rock-building by foraminifera, corals, and shells, etc., we shall speak more fully hereafter. Suffice it to say that great deposits thousands of feet thick owe their existence to small calcareous creatures living in the sea. Coral reefs afford the most familiar illustration.

On land, worms and burrowing animals do a vast amount of work in connection with the soil.

IV. *Heat.*—The force known as heat is of great importance. The earth is hotter below the surface, and probably has a very high temperature towards its centre. In some places not very far below its surface it contains highly heated rock, which occasionally flows over the surface during volcanic eruptions. In other places we find hot springs in connection with volcanic action.

This internal heat supplies the energy displayed in volcanic eruptions. The phenomena of earthquakes are often connected with volcanic action, and may frequently be due to subterranean explosions of steam.

Heat exercises a powerful influence on rocks deeply buried below the earth's surface (see Chapter III on Archæan rocks), chiefly by means of heated water and steam. In this way rocks have been very much altered or "metamorphosed." The crystalline

schists have thus been brought to their present state by a series of chemical changes due to heat; and there is no doubt that they were once ordinary deposits of clay, sand, etc.

We will conclude this chapter with a list of the British stratified rocks. For the sake of simplicity the minor groups, into which they have been further subdivided, are omitted. They have been arranged as follows, in descending order:—

TABLE OF BRITISH STRATIFIED ROCKS.

TERTIARY OR CAINOZOIC.	Recent.	Dominant type Man.
	Pleistocene or Quaternary.	
	Pliocene.	Dominant type Birds and Mammals.
	Miocene.	
	Eocene.	
SECONDARY OR MESOZOIC.	Cretaceous.	Dominant type Reptiles.
	Neocomian.	
	Jurassic.	
	Triassic.	
PRIMARY OR PALÆOZOIC.	Permian.	Dominant type Fishes.
	Carboniferous.	
	Devonian and Old Red Sandstone.	
	Silurian.	
	Cambrian.	Dominant type Invertebrates.
	Archæan or Pre-Cambrian.	

CHAPTER III

AN ARCHAIC ERA

"In these shows a chronicle survives."—WORDSWORTH.

MR. RUSKIN says that "geology does better in reclothing dry bones and revealing lost creations than in tracing veins of lead and beds of iron." It will be our endeavour in the succeeding chapters to bring before our readers in a simple and homely way the results obtained by those great workers whose accurate knowledge of the structures of living things enables them to reclothe dry, and often very fragmentary, bones, and to reveal lost creations to our imagination in their living reality. But we would do more than this; and just as ornithologists, not content with stuffing a dead bird and placing it in a case, love to surround their specimens with such things as shall represent to the beholder their own proper surroundings of rocks, vegetation, water, and such like, so it will be our endeavour to explain the habits and surroundings of those creatures whose remains have so abundantly been preserved, in some cases with a marvellous completeness, in the

stratified rocks; for the rocks in which remains of "lost creations" are entombed often give much information with regard to the physical conditions which prevailed at the time of their deposition. Hence it is possible in many cases to glean a very fair idea from rocks and fossils taken together of the conditions of climate, of the operations taking place, either on land or under water, of the plants and animals, and even the kind of scenery prevailing at a particular geological epoch. And so the work assigned to geologists is not only, as it were, to stuff and set up extinct and long dead creatures, but to restore also their surroundings, or, in other words, to reproduce the geography and natural history of past ages. It is possible in some cases to construct pictures or ideal landscapes showing scenes which no human eyes ever beheld, but such as once met the gaze of a Labyrinthodon or a Pterodactyle.

But with our present knowledge such a scheme can be but partially carried out; the farther the geologist carries his researches into the past the less material does he find for forming such pictures. Also it must be borne in mind that nearly all stratified rocks have been formed under water, and not on land, the exceptions being deposits of blown sand such as are found over large tracts of Asia and America, and materials distributed over islands or continents by the agency of volcanoes, namely lava and volcanic ashes. But even these deposits in the course of time have come under the action of water as subsidence took place, and so have undergone a rearrangement, if not already carried away into the sea by the

mighty agency of denudation. Hence the knowledge already gained of primeval continents is based upon the examination of their débris preserved in the waters of delta, lake, or sea. Water acts in two opposite ways; on land it is the mighty destroyer, at sea it is the mighty preserver—like death to ourselves, the mighty destroyer which sweeps its victims from the land of the living, but also the mighty preserver which brings us into the ocean of eternity.

The earliest known strata present a chaos of metamorphic or highly altered rocks, mingled with others of a volcanic or otherwise igneous origin, without a single safe or certain trace of any plant or animal. But let us be content with what we have; for the volume of the geological record is indeed a great one, consisting of many chapters and thousands of pages. And if the earliest chapter of all—that of the Archæan era—seems brief and incomplete, the fault may be partly ours. Also if the dawn of human history be still enshrouded in darkness and uncertainty, need we be surprised if the dawn of creation on this earth seems also to share that darkness? We may be thankful for even a glimpse: "Distance lends enchantment to the view." The present chapter will be devoted to the consideration and interpretation of the rocks of the Archæan era—the beginning of the record of the rocks. No older rocks than these are known.[1] Their thickness is very great, estimated by some authorities as 30,000 feet; for no base has yet been found in any region

[1] They take their name from the Greek word *archaios*, ancient.

where they are exposed to view. For the most part they consist of gneiss (in many varieties), a rock closely resembling granite, and only differing therefrom in the arrangement of its constituent minerals, which are mica, quartz, and felspar. Schists of various kinds also make up a large part of this great series. In rocks believed to be of the same age in America are large beds of limestone and a considerable amount of graphite (a form of crystallised carbon), and certain iron ores. Archæan rocks are exhibited on a large scale in Scotland, where they were mapped as "fundamental gneiss" by Sir Roderick Murchison, because they were found to be the lowest rocks visible, forming a foundation or platform on which later rocks rest. A large part of the wide-spread gneiss rock of the Central Highlands would seem, according to the latest researches, to be Archæan, though marked and coloured in geological maps as Silurian. But here is a tangled skein; who shall unravel it?—a confused, twisted, and contorted mountain mass of rocks of Archæan and later ages, the denuded wreck of a great complex mountain system like the Alps or the Himalayas.

Archæan rocks are best seen in the counties of Sutherland and Ross, and in the Hebrides. In England it has recently been discovered that rocks formerly considered to be either of igneous origin (that is, due to volcanic action above or below the surface) or highly altered later rocks, in Anglesey, North and South Wales, the Malvern Hills, and (probably) at Charnwood Forest in Leicestershire,

do really belong to the Archaean era. They are generally highly altered. This is only what might be expected from their hoary antiquity. For the older a rock is the more likely it is to be metamorphosed; first by reason of being more deeply buried below the surface, and therefore exposed to the action of underground heat, and secondly because the chances are greater that at some period or other volcanic forces may have been operating in its neighbourhood. When we think of the enormous quantities of hot water and superheated steam which play such an important part in volcanic phenomena, it is obvious that the rocks through which they work their way up towards the surface must be greatly affected. Chemical and other changes must take place whereby shales and sandstones must be metamorphosed into crystalline rocks, such as gneiss and the various kinds of schists.

For the sake of simplicity we have assumed that the Archæan rocks were originally laid down under water (for the most part) like any other strata of later age; but if any doubt this assumption, which is really an inference drawn from important evidence, let them consider if any other explanation of their origin can be suggested. This subject has given rise to a large amount of controversy; but the general opinion is that they only differ from later rocks in being more highly altered, and that the above explanation is correct. This kind of change may be best compared to the baking of bricks: they are put in as stiff clays, sandstones, or calcareous mud, without any crystalline structure; they come

out as schists, quartz rock, and marbles. But it must be borne in mind that the baking undergone has been severe and prolonged, probably repeated more than once, and taking place under the enormous pressure of hundreds and thousands of feet of overlying rocks, and due not to dry heat alone, but to the powerful action of hot water and superheated steam, agents capable of producing most astonishing changes in rocks which come under their all-pervading influence. All attempts on the part of those who once considered these rocks to be the result of a state of things wholly different from the present have failed; for it is not possible to conceive any other origin for rocks which present on the one hand such clear evidence of partial fusion and chemical rearrangement, especially under the microscope, and on the other hand such evident signs of the co-operation of water in their original formation as their arrangement in strata of tolerably uniform thickness and horizontal extent, and their subdivision into thousands of thin layers (laminæ), features highly characteristic of water deposits of the present day. We are now speaking generally, because such observations will not apply in every case; for in some localities (South Wales for instance) it is clear that they are partly made up of great volcanic materials—layers of coarse ashes, and ejected blocks known as "agglomerate," and old lavas. But such might be the case with water-formed rocks of any age; they may be mixed with igneous rocks due to volcanic action prevailing at the time.

In order to strengthen the case we might mention the limestones (marbles) and the graphite found in America; but of these we shall have more to say presently. Finally, it may be urged that it is impossible to conceive of extensive and fairly uniform masses of gneiss and schist, with evident signs of an arrangement into layers of varying thickness, being formed in any other way, than as ordinary stratified aqueous rocks in the first case. Metamorphism is responsible for their present crystalline and much altered state. But this is not all; they bear testimony to changes of a different kind, changes not merely of internal condition and appearances, but of a more striking and obvious nature; they have not been allowed to rest peaceably in even horizontal layers as they were once deposited, but have been violently disturbed—like the blankets and sheets over a sleeper whose night's repose has been far from peaceful, they present a great series of contortions, foldings, and fractures. Even in a small block by the roadside in Scotland one may often see the thin bands of stratification crumpled into innumerable little folds; but such foldings as these sink into insignificance by the side of the greater folds exhibited by these rocks, by the side of which they are of no more importance than the ripples and wavelets on an ocean billow, folds to be measured not by inches or yards, but by furlongs and miles. But the two go together; you do not find the ripples in one place and the waves in another; they are as inseparable as the running zigzag on the Norman arch.

How these contortions and foldings were produced is a question to which much thought has been given; the general opinion now is that their cause must be sought for in the gradual contraction of the earth due to its secular cooling. In this way; the cooling of a heated solid body like the earth implies contraction, and such contraction will take place faster below the crust of the earth than on the cooled and hardened surface; hence as those portions just under this crust cool and contract they must tend to leave an empty space below the crust, or, in other words, leave it unsupported. Then comes in gravity, pulling down the soft unsupported arch, which in its efforts to settle on to a smaller surface must be forced by the lateral pressure thus set up to throw itself into a series of folds, running roughly at right angles to such pressure. That there has been enormous lateral pressure acting on these rocks admits of no doubt; also that it came at right angles to the folds themselves. This process may be illustrated by the wrinkled skin of a dried apple, which in its effort to settle down on to the smaller contracted apple underneath has been obliged to throw itself into a series of folds or wrinkles.

If this be the true explanation, we have here a powerful yet slowly and almost silently working agency, by means of which not only the smallest contortions are produced, but also those great folded and tangled masses of strata constituting the great mountain chains of the world, the upheaval of which always used to be attributed to the violent

catastrophes of the old cataclysmic school of geology. The simplicity and the comprehensiveness of the theory are also strong arguments in its favour. Earth movements are known to be taking place in various parts of the earth at the present day—in some places of elevation, in others of subsidence—but so slowly that years are required for their measurement, and to them in most cases the same explanation is applied; and taking the principle of uniformity previously explained for our guide, we are brought to the conclusion that the minute contortions, the foldings great and small, and the fractures known as "faults" in these Archæan rocks were produced by forces acting quietly and for a long time, depending ultimately upon that cooling of the earth which plays so important a part in the nebular theory.

But it may be asked "Whence came this great mass of rocky material of which we have been speaking?"—a question which may rightly be asked by readers of a book intended for beginners in geology, and for the reading public in general. It has been to some extent answered by the statement already made, that the greater part of the Archæan rocks must have been deposited, like other strata of later ages, by the agency of water, because that implies that the materials were derived from the disintegration and denudation of land surfaces existing at the time, but in themselves of even greater antiquity. What the land surfaces were may never be known. They may have been the original cooled surface of the earth, consisting of

crystalline rocks, or they may have been, for all we know, stratified rocks of a yet earlier age in the world's history. But no traces of such a continent or land surface are visible; its existence is merely a conjecture, and it is very unlikely that any traces of it will ever be seen. But of this much we may be confidently assured, that all those processes of decay, disintegration, and transportation of rock were taking place at this time of which we have so abundant illustration at the present day; rain, wind, streams, probably glaciers, and all the known agents of erosion were at work, wearing down continents and islands and sweeping their débris into the Archæan seas, there to be gently allowed to subside and build up those great deposits now known as Archæan rocks. Their thickness in Canada is estimated at 30,000 feet, and perhaps is quite as great in the British area. It would be out of place to attempt to describe all these processes here. But perhaps we may be forgiven if we quote the familiar words of our Laureate in his *In Memoriam*:—

> "The moanings of the homeless sea,
> The sound of streams that swift or slow,
> Draw down Æonian hills, and sow
> The dust of continents to be."

Here we have a scientific truth beautifully set in a poetic frame; would that poets oftener attempted to sing of the new truths brought to light by scientific men! As we stated before, the working of geological agents may be learned from any elementary text-book on physical geography; but it cannot be too often pointed out that the most unlearned

in geology may learn more for themselves than any text-book will teach them by keeping their eyes open to what goes on around them. For instance, they may gain a clearer idea of the answer to the question asked above than we could give in a whole chapter by watching intelligently what may be seen on the road any very wet day. There they may see the rain beating on the "road metal," wearing it away and washing the débris thereof into the gutters running on each side; if those roadside streams be followed to the bottom of a hill they will see there a big puddle of water brought down by the two streams, and on the morrow, if the rains have ceased, may be seen a flat deposit of sand and mud, the result of the denudation of the road. Need we say any more? The road is the continent; the gutters represent its rivers and streams; the mud flat and the big puddle represent the Archæan ocean and the débris it once contained. But it must not be supposed that what we have said will apply to all the Archæan rocks, though by far the greater part of them may have been accounted for. The intrusive granites and basalts must have had a very different origin, and some of them may have thrust themselves in as intruders from below at a much later date. Still there remain the beds of graphite and the important series of limestone strata in the form of marble; these could hardly have been formed mechanically by any process coming under the head of denudation. How then were they formed? With regard to the graphite, which is only another form of carbon, it may safely be

asserted that such a thing as the deposition of carbon among strata by any process similar to the deposition of sand and mud is impossible; but the graphite veins may have been deposited chemically from liquid hydrocarbons, which, however, leaves the presence of such hydrocarbons to be accounted for, unless we attribute them to the action of internal heat on layers of carbonaceous matter. One great characteristic of carbon in nature is its invariable connection with living matter in some form. It can be got from bones; it is the most important constituent element in flesh. In the vegetable kingdom it is still more prominent. All plants contain a very large percentage of it. The paper of this book if thrown on to a fire would leave a black residue of carbon. The coal we burn is chiefly carbon derived by a chemical process from the atmosphere by the vegetation of the Carboniferous period. Seeing then that carbon seems so inseparably bound up with animal or vegetable matter, its presence is everywhere looked upon as the proof of the former existence of organised matter, and especially of plant life. In fact it is impossible to conceive of the existence of free carbon anywhere on the earth or in the oceans and rivers apart from living matter; if the thing be possible, we have yet to learn by what natural operations such a feat could be accomplished. This being so, the question at once arises, "Is the graphite in the Archæan (Laurentian) rocks of Canada to be taken as evidence of the existence of plant life during that era?" The question is a most interesting one, and has given rise to great controversy. But this is

not all; the grounds of the controversy must be more fully stated. We come at once to the question of the limestones and what they have been found to contain. Now limestones cannot be formed by any process at present alluded to in this book. They certainly have little, if anything, to do with volcanoes and the subterranean forces accompanying them; nor can pure deposits of limestone be due to any process of denudation. In some of the succeeding chapters it will be necessary to enter into this question somewhat fully, but for the present it will be better, in order to avoid repetition, to forestall those chapters so far as to point out the conclusion arrived at by all who have inquired seriously into the question of the origin and formation of limestone deposits on a large scale, which conclusion is this—that all pure stratified deposits of limestone (excluding such as may be formed by the action of springs) have been formed by the agency of organisms living in fresh or salt water, of which the most familiar examples are coral polypes and shell-fish or mollusca. This is firmly based upon the testimony of a cloud of witnesses, great and small, to whose silent voices we will give our attention in the chapters on the Silurian, Devonian, Carboniferous and other periods; to attempt to give them a hearing in the present chapter—already sufficiently long—would be unadvisable. For the present we must ask our readers to accept the bare statement already made.

It was stated above that the Archæan rocks were without a single safe and certain trace of any plant or animal. The reason for this cautious statement

will now be partly evident, but still more so when we have discussed the nature of a supposed "fossil" from the Laurentian marbles of Canada. Yes, even in this unpromising field, a chaotic wilderness of metamorphic schists and gneisses, the eager and all-searching eye of Dr. Dawson has picked up what he considers to be the calcareous framework of a lowly reef-building creature! But the specimens have undergone so much internal and external change that we hardly dare pronounce with certainty whether the structures it reveals under the microscope be really due to living matter, or whether they may not be due entirely to other causes which concern the mineralogist rather than the naturalist. However, Dr. Dawson, believing firmly in the animal origin of his find, has given it the name of "Eozoon," or the dawn of living creatures; hence arose the great "Eozoon controversy," about which much has been written. Sir Charles Lyell, speaking of this remarkable find, says: "It appears to have grown one layer over another, and to have formed reefs of limestone, as do the living coral-building polype animals. Parts of the original skeleton consisting of carbonate of lime are still preserved; while certain interspaces in the calcareous fossil have been filled up with serpentine and white augite." The specimens bear a striking resemblance to an undoubted fossil found in Lower Silurian limestone and known as Stromatopora. The specimens were subsequently examined by the late Dr. W. B. Carpenter. After a careful microscopic examination, these two distinguished observers came to the conclusion that

Eozoon was truly organic, and in this opinion they were supported by other eminent authorities. The opinion of Dr. Carpenter, who has written a masterly monograph on the Foraminifera, to which order Eozoon was supposed to belong, is justly considered to have great weight. On the other hand, Messrs. King and Rowney (taking up the problem from the point of view of mineralogists) have come to the conclusion that the structures in question are entirely of a mineral character.

In the face of this difference of opinion we must leave the specialists to decide for themselves. At the same time the geologist will probably be inclined to take the side of Dr. Dawson, and the reader may add this to the evidence of the graphite and the limestones to help him to form his own opinion. Certainly the three things taken together do present considerations of considerable weight; and unless we can find some other way of accounting for the graphite and the limestones we shall consider the balance of probabilities to be on the side of those who think that the structures known as Eozoon testify to the existence of living marine organisms in the Archæan seas.

CHAPTER IV

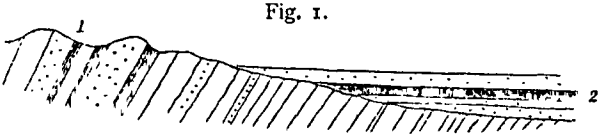
CAMBRIAN SLATES

"Nourishing a youth sublime
With the fairy tales of Science, and the long results of Time."
TENNYSON.

To turn from Archæan rocks to Cambrian is to turn from chaos to order, from darkness to light. In so doing we pass over a great interval of time, an interval marking one of those breaks in the geological record by means of which the whole stratified rocks are divided into four great groups representing the four great eras—the Archæan, Primary, Secondary, and Tertiary. And to these may be added the Recent or Quaternary period, marked by the remains of human beings—an era yet in its childhood. Such intervals or "breaks" are of very great geological value, and the inquiry into their nature is full of interest. The evidence upon which they are founded is of a simple character, and of two kinds: first, there is the *physical break*; secondly, the *organic break*. The first alone concerns us at present. By a physical break is meant a want of continuity and conform-

ability between two groups of strata in contact (the one lying directly over the other), and implying that deposition was not continuous, but was interrupted by some cause (see Fig. 1). The finest example of such a break is that between the Archæan and the succeeding "Primary" rocks. (The term "Primary" was unfortunate, because we now find that they were not the first rocks formed; but we must reluctantly retain it, or use other terms less simple.) A glance at any generalised section of British stratified rocks shows a gap just above the Archæan and below the Cambrian rocks, and further inspection reveals

Fig. 1.



1. Old disturbed strata. 2. Later beds lying *unconformably* upon them.

the fact, indicated by a want of harmony and continuity in the lines of stratification, that the former were not only greatly twisted, contorted, and upheaved *before* Cambrian deposits formed over them, but that they were also considerably worn down and denuded, so that much of their upper part is missing. These simple facts may be made to speak volumes. They are pregnant symbols on the pages of the Earth's autobiography over which we may well linger thoughtfully. Moreover it has been found in Scotland and South Wales that the Cambrian sandstones and conglomerates contain portions of Archæan gneiss and granite which were obviously in that

metamorphic or altered state *before* they were enclosed therein, whereas the sandstones and conglomerates are, as a rule, not so altered.

If the reader should ever seek the western parts of Sutherland, let him there behold the Torridon sandstone resting on its gneissic foundation, and endeavour to spell out for himself the message they bring from the dim vista of the past, and he will find in the attempt a fascination only to be rivalled by the examination of the most ancient historic records.

Briefly the message may thus be read: At the close of Archæan times great foldings and upheavals took place. What was formerly sea became dry land, thus making a great Cambrian continent. This continent, like those of modern times, was long subjected to the destructive work of the agents of denudation. These continued unceasingly their work upon its surface, and wore away and carried down to some other region hundreds, probably thousands, of feet of solid rock, the surface meanwhile probably undergoing a slow upheaval. This old continental surface had its plains, its mountains and valleys, and other features, but whether or not it was clothed with vegetation is a point likely to remain obscure for a long time to come; for there is no evidence at present before the court of geologists who put themselves in the position of judge and jury to the earth to decide upon the nature of her past history. Nor again is there any evidence before this learned court that living animals existed on the Cambrian land surface or continent; but it would be unwise to conclude that such was not the case,

for it must always be borne in mind that "negative evidence" is far from conclusive, and that there is still the possibility that positive evidence may some day be the reward of the all-searching geologist. If such existed their remains may yet be found, or they may have escaped preservation; for creatures living on land as a rule die on land, and so fail to get carried out to sea to a watery grave, where mud or sand may seal them up for ever. Then when denudation had done its work there followed subsidence, the result of earth movements. What had been dry land was once more sea. On this sea-shore, as it retreated, great pebble beaches were formed; by the action of the waves, as at the present day, blocks at first sharp and angular became rounded and smooth. As the water got deeper sand-beds were formed, the result of the continual wear and tear on the shore; but the sand being light could float out some way. Hence the sand-beds were extensive, and for miles and miles beyond the sand-beds, in the deeper waters, mud particles (lighter still) were floating about and slowly settling down to form shales, which in time became the hard slates we now find in North and South Wales. At the same time it is only right to remark that conglomerates may be formed in several ways, and that it is possible that those in the Torridon sandstone of north-west Scotland may have had a different origin. Professor Geikie suggests their formation on land by the agency of glaciers; but that may be entirely local, and therefore inapplicable to the other conglomerates so frequently found at the base of the Cambrian system.

In this little book we can but give general results, and take a general view of each system of rocks as it comes under our notice. Thus there came a sea, the floor of which was formed by the old worn-down and denuded Archæan continent, and thus was introduced the Cambrian period.

What took place in this sea we have now to discover by endeavouring briefly to read the story of the great rocks therein deposited, and since elevated to form dry land and play so conspicuous a part in the physical features of a part of Britain, nay, even in the history of its people; for the geological features of a country have a great influence on its history and its commercial prosperity. Where would the Celtic inhabitants of Great Britain have gone for refuge had there been no mountains to flee unto from their enemies? or where would England be among the nations had not kindly earth movements preserved her valuable coal-fields in depressions not to be worn away by denudation?

Wherever two groups of strata present the relationship to one another which we have described, they are said to be *unconformable* (see Fig. 1). Thus we say the Cambrian rocks rest *unconformably* upon the Archæan; and wherever such is the case it marks a long unrecorded period of time.

The *organic break* is a break in the succession of life, unaccompanied by earth movements in many cases, marking an interval of time for the migration or extinction of one group of creatures and the introduction of another characteristic of the succeeding period. This obviously does not apply to the rocks

we are considering at present; but in succeeding chapters we shall often have to speak of such breaks.

It will now be necessary, in order to gain a proper conception of the events of this period, to turn our attention to other regions where Cambrian rocks may more profitably be studied, and where they contain in no small numbers the embedded remains of a highly interesting collection of marine creatures. Wales is classic ground for the study of Cambrian rocks; indeed they take their name from "Cambria," the northern part of this Celtic country, the home of our Welsh fellow-countrymen, now at peace with the Saxon invader. It was chiefly in North Wales that the revered Sedgwick, for fifty years professor of geology in the University of Cambridge, worked out their sequence with a zeal and ability to which no equal has been found. Many a week, many a month he spent there, mapping them out until, in spite of many difficulties, he reduced them to order. Confining our attention chiefly to the British Isles, because we have here a more complete succession of the stratified rocks than any other country of like size can show, we need only mention three areas of Cambrian rocks, namely North Wales, South Wales, and the Lake District. Considerable difference of opinion has arisen with regard to the classification of these rocks and those of the succeeding Silurian period. The question is where to draw the line between the two. Sir Roderick Murchison, working downwards, took into his Silurian system a large amount of Sedgwick's Cambrian; and Sedgwick, working upwards, included in his Cambrian system

all Murchison's Lower and Middle Silurian. A compromise has since been attempted; but it is quite possible that the two groups will some day be united into one great system, for reasons to be given later on.

In this book we shall follow the classification adopted by Professor Geikie, and include in the Cambrian the Harlech and Longmynd groups, the Menevian group, the Lingula flags, and the Tremadoc slates, thus encroaching to some extent on the Silurian system of Murchison. After all, such divisions are somewhat arbitrary; and if both were included under a new name geologists might for ever banish the memory of this great controversy, and yet equally cherish that of these two justly famous men.[1] According to the classification here adopted, the Cambrian system includes a great series of slates, grits, sandstones, and conglomerates, estimated to reach the enormous thickness of 25,000 feet. A large part is unfossiliferous, but in the upper part fossils have been found plentifully. Fig. 2 shows a horizontal section along the Cambrian rocks of Merionethshire. It will be noticed that they lie in a great upward fold. Whenever such arches of strata are exposed to the surface they are always found to have suffered such great denudation that of the upper strata only the flanks are left; but by drawing dotted lines in such a way as to repeat and harmonise with the curves of the lower strata

[1] Professor Lapworth proposed the term Ordovician for Murchison's Lower Silurian group, and this arrangement has been accepted by some authorities.

it is possible to "restore" the former outline, just as an architect might "restore" a Gothic window from a few portions of tracery still left on the sides. And it is only in this way that an adequate idea can be gained of the enormous denudation many rocks have undergone, and hence also of the enormous lapse of time since their upheaval; for denudation is a measure of time. In this case it is clear that thousands of feet of Cambrian and Lower Silurian rocks have been removed. But it must be carefully borne in mind that all such horizontal sections have their vertical scale exaggerated, for the simple reason that if drawn on a true scale the strata would be invisible, their thickness being insigni-

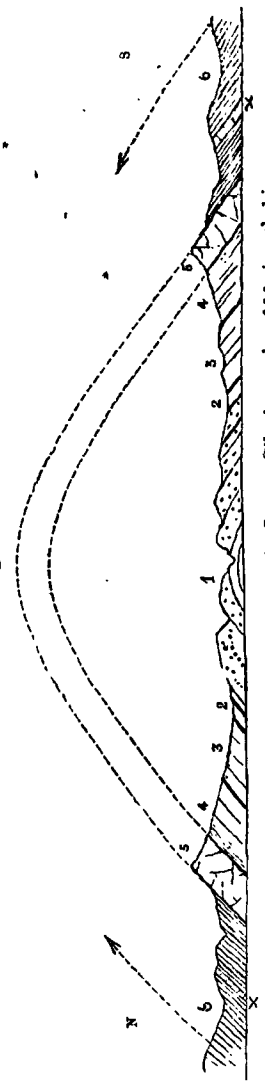


Fig. 2.

Section across the Cambrian and part of the Lower Silurian rocks of Merionethshire.

1. Cambrian grits. 2. Menevian. 3. Lingula flags. 4. Tremadoc and Arenig slates. 5. Igneous series. 6. Llandeilo and Bala. × Bala limestone.

ficant compared with the length of the section. This causes the height of the dotted lines to be too great. When strata are thrown into a downward fold they are said to lie in a trough or "syncline," and it is found to be an almost invariable rule that anticlines have been worn down into valleys, while synclines form mountains; because the latter structure is stronger, more compact, and better able to resist denudation, while the heaved-up arch will be a good deal cracked and loosened, and therefore in time succumb to the forces of disintegration (examples will frequently occur in the succeeding chapters). Thus it comes to pass that in process of time "every valley shall be exalted, and every mountain brought low" by the ceaseless operations of the gentle elements; and thus we learn that the words of the great Hebrew prophet have their counterpart in the material world.

Without proceeding further to describe the lithological character of Cambrian rocks in other regions, it may be generally stated that they consist of an enormous series of schists (in some places), slates, sandstones, grits, and conglomerates, associated in some areas with intrusive dykes of igneous rock, volcanic lavas, etc., roughly estimated to have a thickness of 30,000 feet. Such estimates are of course only approximate, on account of the great difficulty of obtaining an accurate measurement of a series of rocks so much contorted and displaced by "faults," and which cannot be seen completely developed in any one area.

Let the reader, in order to gain some idea of the

task, take half-a-dozen old dusters or cloths of different colours, cut some large holes in each, place them flat on a table one over the other, but partly overlapping, then squeeze them into a series of folds like mountain chains, and endeavour with tape or ruler to measure up correctly their united thickness (previously ascertained) without in the least disturbing them. Even then he will have a far easier task than the geologist wandering on the Cambrian hills, because there will be no "faults" interfering with their relative positions, no difficulty in determining which is which; and also because he can look down upon them and take a general view, which the geologist cannot do.

It now only remains to make a brief survey of the fossil treasures which these rocks have yielded, and then to sum up the evidence of rocks and fossils together, in order to form some idea of what was taking place in this part of the world during Cambrian times. It will only be possible in this book to describe briefly and in simple language a few of the most interesting forms of life of each period, so the reader who would have a fuller knowledge should consult a good text-book; but we would strongly advise all who are interested in geology to rely chiefly upon a practical acquaintance with rocks and fossils gained, if possible, in the field, and to frequent museums as often as opportunities can be found. The best of all museums is the new Museum of Natural History in Cromwell Road, a national treasure-house of which we may well be proud, a place which we hope will prove more and more

attractive to the youth of England as year by year the knowledge of creation's wonders plays a larger part in our national education.

There is a peculiar charm to the geologist in the contemplation of the fossilised remains of the earliest groups of living things yet known to have existed on the face of the earth, and a still greater charm for those who have the leisure to hammer them out of their native Cambrian rocks, just as there is a peculiar wonder in beholding the earliest known ruins or works of art belonging to prehistoric times; but in neither case is it unlikely that still older treasures may yet be unearthed from their hiding-places below our feet; so we venture to think our readers will experience a new pleasure if they will go to some good museum and find their way to the cases marked "CAMBRIAN." There they may behold a gathering of the most ancient fossils known, all neatly labelled and placed together according to their proper positions in the scale of life. "What shall I see there," you may well ask, "fishes, or dragons, and sea-monsters?" No, but only humble little creatures that once swarmed in a muddy or sandy bottom in the shallow Cambrian sea, and strange markings which have yet to be explained. To begin with plants, there can be but little if any doubt that marine plants thrived in this ancient sea; but the traces they have left are so obscure and difficult to determine that very little can be said about them. Some curious impressions found at Bray Head (County Wicklow) by the late Dr. Oldham may be the traces of a calcareous sea-weed; but

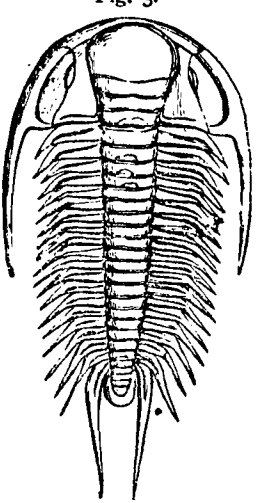
it is quite possible they may have been due to an animal organism, as some of the present day "sea-mosses" and "sea-firs" have forms not unlike these impressions (known as Oldhamia), and it must be borne in mind that the lowest animal, and the lowest vegetable forms, are not so easily distinguished as their higher relations; in fact, naturalists tell us that some of the lowest forms of life can hardly be assigned to either one or the other kingdom. Jelly-fish were living then, for their impressions have been found in Cambrian slates. The earliest known sponges may here be seen—curious little bodies composed of netted fibres. Corals are not to be found in any collection of Cambrian fossils; but then they are hardly to be expected on account of the absence of limestones, the great hunting-grounds for corals; that they did exist somewhere in these times may be readily believed, since they were abundant during the next period we shall have to consider, namely that known as the Silurian. The sea-urchins, those round prickly little wonders of our sea-shores, had their part to play even then—probably as scavengers, ready with their powerful teeth and strong digestive powers to eat up almost anything that might come in their way. But if we could have looked into the Cambrian seas, as we can now see from a boat the creatures living in clear shallow water near the shore, we should have seen also their more beautiful relations the sea-lilies or crinoids, and cystideans, with their beautiful cups and waving branches looking like corals. The star-fish, a familiar object to the sea-shore wanderer now,

also had its haunts in this Cambrian sea. One of these (Palæasterina) may be seen figured in several of our text-books. The ringed worms (Annelida) appear to have swarmed, to judge from the number of their burrows found in some Cambrian rocks, especially those of the Longmynd in Wales. Besides these burrows are found meandering trails caused by the worm dragging its body over the surface of the mud. But some other curious markings are not so easily understood; in fact, it is hopeless to attempt their explanation until more careful attention has been given by naturalists to the habits of marine shallow-water creatures of the present day. This can only be done properly by diving, and watching them to see what kind of tracks they make as they move along; and so a more accurate knowledge of the present would, as we have before pointed out, greatly help the interpretation of the past.

Creatures rather like shrimps lived in these times, for their impressions have been found in the Lingula flags. But the most interesting of Cambrian fossils are the *Trilobites*, members of the same class as shrimps (the Crustacea), but belonging to an order now quite extinct; they must have literally swarmed in the seas of the Cambrian and Silurian periods. Like other crustacea, their soft bodies were enclosed in a hard covering such as crabs and lobsters have, and this is of course the only part now preserved; nor is that complete, for their numerous and delicate little legs got broken off after their death, as so often happens to crabs now, so that we often only find on the sea-shore the hard covering minus the legs;

that they had legs seems now, after a long controversy, quite settled. They had eyes too, as crabs have, but they were never carried on movable stalks, as in the existing crabs and lobsters, though in some cases they are supported on prominences; so excellently are they sometimes preserved that the numerous little lenses of the eye have been left uninjured, and as many as four hundred have been counted in each eye of some. The body, except the head and tail, was divided into a number of rings, so that in some cases where they were more flexible the animal could roll itself up into a ball, as woodlice do now, in which state they have been found fossilised, and it was by the careful microscopic examination of their sections cut from such specimens that the former presence of soft membranous legs was detected; probably this was one mode of self-defence.

Fig. 3.



A Cambrian Trilobite (*Paradoxides*).

The Trilobites vary very much in size, some being no bigger than a millet seed, while the giants of the order, such as *Paradoxides*, were nearly two feet long (see Fig. 3). Judging from their structures and what is known of their modern relatives (the king-crab and the woodlice), it would seem that they were mud-haunting creatures, loving the soft silt of the bottom rather than the clearer water above.

They crawled about on the muddy bottom, and probably fed upon the organic matter which such muddy ooze would contain; indeed, numerous tracks and markings found in the same rocks with these creatures would seem to be the very tracks they made when alive.

Several geologists have paid great attention to the study of these interesting creatures; their eggs have been found in clusters, and some specimens are probably young ones not fully developed, killed before their prime.

Lastly, the reader will be sure to find in any good collection of Cambrian fossils certain little "shell-fish," or mollusca. One of these, Lingulella, is found in a quarry near Tremadoc; it is a little bivalve shell, of peculiar interest from the fact that a very similar shell exists at the present day, by means of which a very good idea of the anatomy of its very ancient ancestor may be gained, namely the "goosebill" lampshell (*Lingula anatina*).

Higher forms of mollusca than these were not wanting, though only a few traces have been found; but they tell us that even in these early times there were forms of life not unlike our chambered shell-fish, the nautilus and its allies. One of these (Orthoceras) is like a nautilus unrolled into a straight cylinder. These are not all the Cambrian fossils, but they are perhaps the most important, and such as may well find a place in this book.

It has been stated that the Cambrian rocks were deposited in a shallow sea, and there is much evidence in support of this; for besides the presence of worm-

tracks and burrows, geologists have found sun-cracks and marks of rain-drops, clear evidence that at times when the tide was out the hot sun dried the mud, causing it to crack, and that when showers came the rain-drops left their impressions; and after the rain the sun came out again and hardened them, so that when once more under water they were not obliterated, but only filled up with soft undried mud. Numerous ripple-marks have also been detected, another proof of shallow water conditions.

Again, the absence of limestones points in the same direction; for marine limestones can only be formed far out to sea where the supply of sand and mud from the land has failed. In the deepest and most remote parts of the seas of the present day only calcareous ooze is collecting. Also there can be no doubt that during this long period a gradual subsidence was taking place, otherwise it would have been impossible for such a vast series of rocks to have been accumulated. In fact all the great periods of deposition of rock material have been periods of subsidence. Upheaval must in time raise the sea-bottom into dry land, and then the deposition of material for future rocks ceases.

CHAPTER V

THE SLATES AND ASHES OF SILURIA

"All the world's a stage."—SHAKESPEARE.

As Sedgwick christened his Cambrian system of rocks after the ancient name of North Wales, so Murchison gave the name Silurian to his great system, naming it after the Silures, an old Celtic tribe formerly inhabiting a large tract of Wales, whose memory the science of geology thus perpetuates. The interesting chapter of the earth's history contained in these pages of stone we must now endeavour to read in its main outlines. "But," the reader may ask, "how do you know which are Cambrian and which Silurian rocks? Are there any titles to these ancient chapters?" To which we answer that there *are* titles, contained within: how these titles are read we will first endeavour to explain. Now since geology is only another kind of history, it would seem probable that the same principles which guide the archæologist searching buried cities might also guide the geologist in ransacking the ages, not of human history, but of the planet on which that history has been enacted as

on a stage. When our poet wrote "All the world's a stage" he thought only of "men and women" whom he called "merely players"; but the geologist sees a wider application of the words as he reviews the great drama of past life on the globe, and finds that plants and animals too "have their exits and their entrances." Nay more, the "strange eventful history" of a human life sketched by the master-hand might well be chosen to illustrate the birth and growth of the tree of life, the development and expansion of which we shall briefly outline from chapter to chapter as we proceed on our survey.

The two principles by which the archæologist—in the absence of written or sculptured records—determines the age of any particular layer or stratum of débris and ruins are these—

1. The position of the layer.

2. The nature of any works of art, etc., it may contain.

Thus it is obvious that the lowest layers must always be the oldest. Now the geologist adopts the same principle, and lays it down as an axiom that the lowest strata are the oldest, and the highest the newest, unless by subsequent disturbance the order should have been reversed, which, however, is fortunately a rare occurrence.

It is entirely on this principle that the Archæan rocks, described in Chapter III, are considered to be the oldest known rocks; hence they have the lowest place in the list of stratified rocks.

Now the second guiding principle is also fundamentally the same as the second method of the

archæologist. Suppose, for instance, that the lowest layers discovered in a buried city contain some very crude works of art, and that the higher layers contain others, showing by the greater skill and artistic taste required for their production a higher state of civilisation, will not such evidence be naturally taken as another proof of the lapse of a considerable number of years or centuries in the history of that city's community?

But, further, the expert with a knowledge of the rise and progress of some great nation, such as Egypt or Assyria, would be able in most cases to fix approximately the age of a piece of work, just as even a little knowledge of architecture tells the visitor to Salisbury Cathedral that it belongs to the Early English period of Gothic architecture. So it is in geology. Fashions or "styles" have prevailed among members of the animal and vegetable kingdoms of the earth; and on each, in spite of certain exceptions, the law of progress is clearly written.

To put the matter briefly, it is found that fossils are not scattered up and down the rocks promiscuously, but that certain kinds of fossils belong to certain rocks. For instance, a lifelong search for ammonites among Primary rocks would be fruitless, since ammonites are only found in, and are characteristic of, Secondary rocks. So would be a similar search for trilobites among Secondary rocks, for trilobites are characteristic of Primary rocks. When the Secondary period began trilobites had died out. They had their "exit"; but ammonites had their "entrance."

So with regard to the Tertiary period, when certain great quadrupeds, like the Megatherium, flourished long after the extinction of many Secondary reptiles. But palæontology or the study of fossils helps us much further than this; because certain genera and species are characteristic of certain subdivisions of the rocks of these eras, called periods, such for instance as the Cambrian or Silurian, and certain genera of trilobites are distinctly Cambrian as others are distinctly Silurian. In fact the process of separation can be carried still further; for practical geologists working in the field use fossils as their main guide in working out the subdivisions of a group of rocks such as those just mentioned. If the reader will take up Murchison's work, *The Silurian System*, he will find many sets of fossils mentioned and described, each from some small subdivision of Silurian rocks. In this way a certain order of succession has been established once and for all, an order invariably found to hold good; and, except in the rare case of strata being inverted, one could no more find Cambrian fossils succeeding Silurian fossils than one could find a cathedral with Norman work built on to Early English. This great discovery of the order of succession of the British stratified rocks, established by their fossil contents, is due to William Smith, the father of English geology, who published his *Tabular View of the British Strata* in 1790. Afterwards he explored the whole of England, and in 1815 published, as the result of his extraordinary labours, a geological map of our country, thereby winning everlasting fame. It

is not difficult to see how, by combining these two principles together, the geological age of any group of rocks may be determined. Thus if a group of rocks of unknown age can be shown to rest on undoubtedly Silurian rocks in one place, and in another to be overlain by undoubtedly Carboniferous rocks, they will probably belong to the Old Red Sandstone period. Should subsequent researches prove them to contain Old Red Sandstone fossils, the question of their age may be regarded as settled.

According to the classification of Sir Roderick Murchison the Silurian rocks are divided into seven subdivisions, each with a name taken from some locality. Their total thickness is estimated at 18,500 feet, and they consist chiefly of sandstones, slates, and bands of limestone. Like their predecessors, they are in Great Britain much disturbed and contorted, heaved up here into an "anticline," there depressed into a "syncline," and have also suffered much denudation, thousands of feet of solid rock having been worn away from the present surface of North Wales. That these rocks are of marine origin can admit of no doubt; their fossils are in every case the remains of creatures whose home was the ocean. They were slowly deposited at the bottom of the Silurian sea during a very long period of depression, the sandstones and conglomerates near the shore, the shales (now altered into slates) and limestones in deeper water.

A very little search among Silurian rocks in Wales would enable the reader to find a block of slate with many bands of stratification, each marking

a separate layer of deposition. Let him then consider how long each of those little layers (once soft mud) took to form, by such almost imperceptible processes as are now taking place in the sea, and then ask himself if, by any stretch of imagination, it is possible to form an idea of the length of time required to build up thousands of feet of such strata, and he will then perceive how impossible it is to express in years the duration of the Silurian period. By what means the slates of Wales, both Cambrian and Silurian, acquired their peculiar property of splitting up in a certain direction, when struck, into innumerable thin sheets, so convenient for slating roofs, was a puzzling question to geologists some years ago. After various suggestions had been made it was found a similar power of splitting up, that is a "cleavage structure," could be produced artificially in other substances by the application of considerable pressure. Professor Tyndall succeeded in producing a "cleavage structure" in beeswax and other substances in this way. Now when rocks possessing this structure are examined they are found to give proofs of their former subjection to great pressure, of which perhaps the most striking is the distortion or deformation of fossils contained therein. Thus trilobites in Silurian rocks are often found to be very much out of shape. Microscopic examination of these slices of slate shows the same thing, and if other proof were wanting it may be found in the fact that such rocks are often greatly contorted and folded. But in some countries something more than lateral pressure and disturbance has

taken place, and Silurian rocks are found to be metamorphosed into schists, and even into granite in some places, as in Scotland. But in other parts of Europe and America they are seen to be so little altered and so slightly disturbed that, judging from the appearance of the rocks, their immense antiquity would be hardly credible, were it not for the fossils they contain.

The three lowest groups—the Arenig, Llandeilo, and Caradoc or Bala beds—are of exceptional interest, from the fact that they were to a large extent formed by the agency of volcanoes. For a thorough comprehension of the means by which these volcanic rocks were formed, it would be necessary to possess a considerable knowledge of volcanoes and the phenomena of volcanic eruptions; but it will be sufficient for our purpose to point out three important actions due to this cause, and then to show that such actions took place during these times over part of the area now known as Wales.

In the first place, volcanoes are known to be capable of emptying enormous quantities of molten rock from their craters and sides, which runs down and spreads often over many square miles of country. Secondly, a more frequent result of an eruption is the production of a tremendous shower of ashes and "lapilli" (or small stones), accompanied by the ejection of larger blocks and portions of semi-liquid rocks known as "bombs." Such volcanic showers may last for many days; their cause must be sought for in the great expansive power of super-heated steam bursting with explosive violence through the molten lava in the crater and

reducing successive portions of it to the finest powder, like water shot out of a gun, while the lapilli and larger blocks are portions torn off from the sides of the crater, or from the rocks underlying the volcanic cone. Thirdly, portions of liquefied rock below the volcano, unable to find an outlet up the orifice, are forced into any joints or cracks there may happen to be in such underlying strata. Should the surface be reached they form a "minor cone" or another big volcano, as the case may be; but if not they must stay there, and finally, on cooling, solidify into so many wedges of solid rock, known to the geologist as igneous "dykes." Now these interesting volcanic rocks may be studied in the Arenig mountains, or Snowdon, or in Cader Idris, all in North Wales (see Fig. 2). We will take Snowdon as the most familiar.

Should the reader some day climb this beautiful mountain, he will do well to take a hammer, a pocket-lens, and a geological map, and thus equipped to search for himself. A section through Snowdon shows grits overlying slates, then a great layer of felspathic lava, and near the top hardened ashes and lapilli. Now this lava flow probably took place under the sea, and these old Silurian volcanoes were therefore submarine; but they would nevertheless act pretty much in the same way as terrestrial ones, and easily overcome the resistance of the weight of water above them when in action. Now the ash-beds are stratified in a very regular manner, showing that they fell down into the sea and were allowed slowly to settle down and become stratified, just like

the ordinary mud washed off a continent or an island. This is proved by the fact that fossil shells (or their casts) of undoubtedly marine character are found in these ash-beds. It means that while showers of ashes were falling into the sea certain shell-fish were quietly living at the bottom, and there got buried up, much in the usual way. But these strata are so compact and hardened that they are at first easily mistaken for the felspathic lava; where, however, they show a weather-beaten surface the small lapilli and little rounded felspar crystals are easily detected, and then there can be no doubt which you are looking at.

It is perhaps hardly necessary to say that no trace of a volcano is now to be found; Silurian volcanoes have been denuded away ages ago, leaving only the lava-flows, dykes, and ash-beds, and those very much cut up and worn down by subsequent denudation. Hence, it is not true to say (as the writer has often heard it said) that Snowdon was once a volcano. A great volcanic series of rocks of the same age is also to be seen in the Lake District, formed in the same way, and with a thickness of nearly 12,000 feet. Having spoken of the rocks of this period, we must now turn our attention to their fossils, the number of which is very great compared with those of the corresponding period. M. Barrande published a census in 1872 in which the number of species was put down at 10,074. All these are undoubtedly marine forms of life; hence we have no knowledge of the land surfaces of these times which must have furnished a large part of the detritus of which these

rocks were formed. One might have expected at least a few land-plants among all these remains, and a few have at last been found; yet the only other relics of vegetation upon which a positive opinion can be expressed belong to the obscure group of "Fucoids," and are supposed to be the remains of sea-weeds. Spores of a lycopodiaceous plant have been found, a supposed fern, and some true lycopodiaceous plants. Hence we may conclude that a cryptogamic vegetation, chiefly of ferns and lycopods, existed on the land surfaces of this period.

The chief zoological groups to be noticed in a complete collection of Silurian fossils are the foraminifera —delicate little shells of lime of microscopic size, but of great beauty, about which we shall have more to say in the chapter on the Carboniferous limestone— graptolites (or "sea-pens"), encrinites (or stone-lilies), corals, trilobites (relations of the king-crab), mollusca (or shell-fish), and remains of true fishes. The latter make their appearance here for the first time; and on account of their possession of a backbone are higher up in the scale of life than any of the others. This gradual introduction of higher forms is a very striking feature of the geological record, and one which bears important testimony to the truth of the doctrine of evolution; in fact it would not be too much to say that the science palæontology, unaided by the light of this new teaching, becomes a meaningless mass of facts.

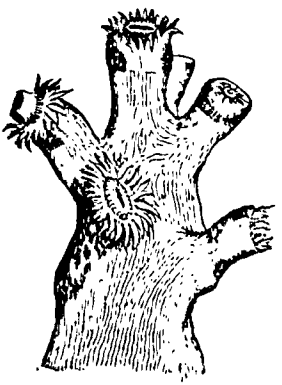
Among the most plentiful of the denizens of the Silurian sea must have been the little graptolites (or "sea-pens"), so called from the Greek words "grapho,"

I write, and "lithos," a stone, because of their resemblance in some cases to written or pencilled marks on a stone. They were once a thriving little colony of "polypes," each one of which lived in a horny little cup or cell, while the trunk or common stem of the colony was protected by a delicate horny sheath. Trilobites too must have been very abundant, 1611 species having been found entombed in these rocks.

The Silurian limestones, such as the well-known Wenlock limestone, slabs of which are frequently found crowded with fossils in a beautiful state of preservation, are chiefly formed of the remains of encrinites, corals, mollusca, and trilobites; but we must defer to a subsequent chapter any attempt to explain properly the formation of limestones. There can be no doubt that coral reefs were present in the Silurian sea, since many of the corals are such as build reefs, and in some places the limestones are simply old coral reefs buried up amongst other strata. The reader would not find it difficult to picture to himself these reefs after reading accounts of modern coral reefs and coral islands from books of travel or treatises on natural history; but we shall have more to say about coral reefs subsequently (see Chapter XII). In general structure these corals differ but little from ordinary corals of the present day, and doubtless their polypes were as beautiful and gorgeous in colours as their modern descendants the madrepores (see Fig. 4). The trilobites, so numerous and of such divers types, were not the only Silurian members of the crustacean class; for the remains have been found of some much

larger creatures, of a more lobster-like pattern, to which the family name Eurypteridæ has been given in allusion to their broad oar-like swimming limbs. They too seem to have existed in great numbers in the muddy shallows of certain areas. Their nearest living allies are the "king-crabs" (*limuli*) of the China seas. We will not attempt a detailed description of these strange creatures, which rather remind us of scorpions in appearance. We shall find them appearing again in the rocks of the succeeding period (Old Red Sandstone).

Fig. 4.



A Living Coral.

Lastly, the remains of Silurian fishes are of great interest, and the reader should carefully note that their first appearance, as far as is known at present, does not take place until after all the great sub-kingdoms of invertebrates had long been in existence; and there is no reason to think that future discoveries will alter this *relative* order of succession.

The lower Silurian rocks have yielded some little bodies called "conodonts" found in great numbers in Russia, and considered by some to be the teeth of certain kinds of fish, but there is considerable doubt about this conclusion (not shared by Professor Owen). However, the Upper Silurian rocks have yielded unmistakable fish remains, representing two very different

kinds of fishes, known to naturalists as "ganoids" and "placoids"; the former order is now very nearly extinct, though in those times they must have been very abundant. The ganoids differ from all other known fishes in possessing a complete armour of bony plates and having a very feebly developed internal skeleton or backbone. There are just a few places on the earth where, in spite of competition with later forms, they have lived on to the present day; but their ultimate extinction is as probable as that of the North American Indians. The only living descendants of this once powerful order are the garpike of North America, the polypterus of the Nile, the sturgeon, and a few others less known; and it is very fortunate for the palæontologist that he has these modern representatives to aid him in his study of the fossil forms. The sturgeon is often to be seen in our fishmongers' shops, or, better still, living in some of our public aquariums. Should the reader happen to see them in this way, he will then be able to get a very good idea of what a ganoid fish was like. In that delightful *Song of Hiawatha* there is a description of the sturgeon which we feel sure we may be forgiven for quoting:—

"On the white sand of the bottom
Lay the monster Mishe-Nahma,
Lay the sturgeon, King of Fishes;
Through his gills he breathed the water,
With his fins he fanned and winnowed,
With his tail he swept the sand-floor.
There he lay in all his armour!
On each side a shield to guard him,
Plates of bone upon his forehead,

Down his sides and back and shoulders
Plates of bone with spines projecting!
Painted was he with his war-paints."

The other Silurian fish-remains belong to the placoid order, resembling our modern sharks and "rays," and are found in the remarkable "bone-bed" near the top of the Ludlow group of strata. Some of these remains are slightly curved spines, and doubtless were similar to the strong defensive spines possessed by sharks and other modern fishes.

This concludes our brief survey of the Silurian period, a long time very far back in the history of this planet, but yet for all that a time when the operations of nature were taking place very much as we see them now. Rivers brought sediments into the sea, with its varied forms of *in*vertebrate life and its fishes; volcanoes were at work performing such operations as they do at the present day; and coral reefs were slowly built up by the wonderful agency of innumerable industrious little polypes. But the life of these times was very different. There is no evidence at all of the existence of any forms higher than those already mentioned; and so we must conclude that there were no reptiles, no birds, no quadrupeds.

Truly the world has not stood still since the Silurian period!

CHAPTER VI

THE OLD RED SANDSTONE

"Geology is the science which investigates the successive changes that have taken place in the organic and inorganic kingdoms of Nature."
SIR CHARLES LYELL.

THE Old Red Sandstone rocks may be found not far from their predecessors of Silurian age in Wales and Scotland. They are so different in colour and appearance, and produce scenery contrasting so strongly with that of Silurian districts—bold, gently rounded hills and fertile plains, with orchards and gardens, instead of bleak and rugged mountains or wild glens—that no traveller could pass from one to the other without noticing the change. A mere glance at the buildings, churches, houses, or walls would suffice to announce his arrival into a new geological area where deep-red sandstone is used instead of slates, flags, or basalt. An examination of a block of Old Red Sandstone, for which purpose a pocket-lens, a hammer, and a penknife are indispensable, tells us that it is made up of innumerable little grains of sand (which is quartz or silica)

cemented together by oxide of iron (iron rust). But sometimes you will find actual pebbles of quartz, and if these become numerous you have a conglomerate. Conglomerates are frequent in the Old Red Sandstone, and in some cases of enormous thickness. But the pebbles are not always quartz; they may be of granite or gneiss, and sometimes are not rounded, but rather angular, like transported blocks of stone. We must now pass on from the consideration of the fragment to the parent strata from which it was derived, in order to gain a general idea of their nature.

The two chief areas of Old Red Sandstone are South Wales (with portions about Bristol and on the Mendips) and Scotland. Be it remembered, however, that nearly all our British stratified rocks are only to be seen as it were in fragments: in some regions they have been swept away by denudation so that lower rocks are now seen at the surface; in other cases they are largely concealed by the subsequent deposition of overlying and new rocks. Hence for both of these reasons only fragments of the Old Red Sandstone are now to be seen; but the fragments are amply large enough for our purpose.

In South Wales may be seen a great group of strata—shales, sandstones, bands of nodular limestone (corn-stones), and conglomerates—with a thickness of 10,000 feet, passing without any break or "unconformity" into Silurian strata below, and into Carboniferous strata above. In Scotland these rocks are exhibited on an even grander scale, and can be separated into two groups divided by a strong

"unconformity," and also by a complete break in the succession of fossils, its total thickness being considerably over 20,000 feet. But to return to our block of Old Red Sandstone. There can be no doubt that it was formed under water; for the remains of fishes are found in these strata. But where did the little grains of quartz come from? Most probably they have been washed out of ancient igneous rocks, many of which, like granite, contain free quartz; or perhaps they come from highly altered strata of Archæan age, such as may then have been exposed at the surface. Anyhow we may be quite sure that each of these little grains came from some older rock, and has been carried by streams for many a mile, getting its corners rubbed off and so becoming round, until at last it found a resting-place in the waters of the Old Red Sandstone period.

Then comes the question how these rocks got their red colour, and what does it mean? It means a great deal. The colouring material is made of iron, the presence of which, seemingly so unimportant, presents valuable evidence to the geologist, and, together with other matters about to be mentioned, leads to highly interesting conclusions. It has been pointed out that the red oxide must have been precipitated from solution round each grain of sand in the waters of a great inland sea or lake; because no such chemical process could take place in the open sea. This then is the interpretation of the red colour —a symbol in the language of the rocks the meaning of which long remained hidden. Having therefore heard the evidence of the red oxide, let us call up other

witnesses. First come the land plants—ferns, lepidodendrons, conifers, etc.—the remains of which are partially preserved in those strata. And what is their message? Surely they testify to the neighbourhood of land; for an inland sea or lake would be a likely resting-place for any dead plants or trees which the rivers of a continent might be carrying on their surface. To this we must add the testimony of the fossil fishes found in these rocks, most of which are ganoids, whose nearest representatives are certain modern ganoids inhabiting rivers in Africa and Australia at the present time. One of these, the polypterus of the Nile, is extremely like a well-known fossil fish of this period (Osteolepis); and it is a striking fact that in Lake Superior and other inland Canadian seas we find this old ganoid type of fish flourishing. If the rocks we are considering had a marine origin we might naturally expect to find the remains of marine shell-fish (mollusca) preserved in them; but such are conspicuous by their absence, with one or two local exceptions. Geologists have only found one mollusc, and that was a fresh-water mussel (anodonta) from Ireland. That some marine forms of life—great crab-like creatures—have been found does not upset the above conclusion, but seems to point to the existence of brackish water, which doubtless in time became more and more diluted by the influx of rivers, until it was almost like fresh water. Some of the fishes were able to adapt themselves to these conditions and lived on; but others less fortunate succumbed to the change and became extinct; for even in those times the "struggle for

existence" was maintained, and only the fittest survived.

Now if at the close of the Silurian period a gradual upheaval and lifting up took place, by means of which the old sea-bed was lifted above sea-level and became a continent, and left here and there depressions forming great inland seas or lakes, it would be natural that by far the greater part of the old Silurian forms of life, being truly marine, should migrate and disappear; and this is just what seems to have taken place; for where Silurian rocks are found to be overlaid by Old Red Sandstone, it is very striking to see how suddenly the abundant and varied life of that period almost vanishes, and the overlying rocks are nearly destitute of fossils, though the Silurian strata are full of them.

Professor Ramsay, who first put forward this view of the origin of our Old Red Sandstone, points out that seals somehow manage to live in the inland freshwater lakes of Newfoundland, and that the same is the case in Lake Baikal in Central Asia; and if seals can thus adapt themselves why should not fishes? He considers that these and other inland seas, like the Caspian, may be taken as faithful types of the inland seas of Old Red Sandstone times.

The Caspian Sea was once united with the North Sea, but has been disunited from the ocean and now contains very few living creatures. But if an increase in rainfall took place, it is conceivable that the many salt lakes this region contains might all become fresh and overflow, until they covered a space as large as the Old Red Sandstone area of Europe. In

this case he thinks we should have an admirable illustration of the gradual change by which the inland seas of the Old Red Sandstone period became fresh-water lakes. But we have not been able to do full justice to Professor Ramsay's arguments, because they are strengthened by other facts concerning some red rocks of later date (known as the New Red Sandstone) which seem to have had a somewhat similar origin. In a later chapter we will endeavour to put these facts before the reader. Not a little of the interest with which the geologist regards the Old Red Sandstone rocks is due to the fact that they speak of a land-surface, a continent such as Asia of the present day, with rivers, mountains, volcanoes, forests of primitive vegetation, and perhaps glaciers creeping silently down their valleys into plains clothed with grass such as we see now; and since this is the first glimpse we get in the geological record of a land-surface, there is a peculiar fascination in the endeavour to picture it to our imagination and to people it with living things. True there must have been continents in existence before then, but we have no record of them such as we have here, whereas among the Old Red Sandstone rocks we seem to be face to face with inland lakes, volcanoes, primeval forests, and all the scenic elements of a modern continent.

Let us now consider for a moment the conglomerates which we have already mentioned. Do they not speak to us, some of them at least, of mile upon mile of pebble beaches, the work of the ever restless sea, as by a gentle upward movement the old

Silurian sea-bed was lifted up to form the shores and inland seas of a new epoch in our planet's history? There was plenty of material to hand for the waves to work upon, and they did their work well. Blocks of quartz rock and gneiss were broken and worked up into smooth round stones, soft mud filling up the spaces between and cementing them at last into hard conglomerate.

Then, when our continent had been well established, we may fairly conclude that each of its lakes had a fringe of more or less rounded pebbles and stones on its shores, such as you may now see round almost any Scotch lake. Can we not picture to ourselves the hills standing round and their streams running among them, the great masses of loose stones or "screes" below each crag or precipice, just as you may see them now in Wales or Scotland, testifying to the influence of heat and cold, rain and snow? As it is now, so it was then.

Mountains, however old or however hardened in texture, suffered decay, and their débris was carried down by torrents into the plains and valleys beneath, there to be buried up and so preserved for our diligent study. Professor Ramsay considers that some of these conglomerates may have been formed by the action of glaciers, or, in other words, that they may be glacial "moraines" formed in the same way as those so familiar to travellers in Switzerland, where glaciers slowly creeping down their valleys transport large quantities of mud and stones down to the lower regions, and glacier streams transport them to the plains below (see Chapter XVI). But before

such a conclusion can be established it will be necessary to find more convincing proofs, such as the familiar "striæ" or scratches caused by the friction of stones embedded in ice against the rocky floor of the bed of a glacier. If any geologist can find true striated stones in our Old Red Sandstone conglomerate, then Professor Ramsay's surmise will be raised to the rank of an established fact, and a new element of interest added to the study of our Old Red Sandstone.

But there is yet another way of accounting for some of the conglomerates. They may be volcanic, especially when associated with rocks of volcanic origin, such as lava-flows and ashes, and when the stones are sharp and angular like those in a modern volcanic "breccia" (a mass of fragmentary materials from volcanic rocks). For we have abundant proof that volcanic action took place on a prodigious scale during these times, the evidence of which may be best seen in the Lower Old Red Sandstone strata of central Scotland, where the geologist finds lava-flows and ashes, etc., with a thickness of more than 6000 feet, fragments of which, having escaped denudation, now form important chains of hills, such as the Pentland, Ochil, and Sidlaw ranges. Nor was volcanic action confined to this region. In the district of the Cheviot Hills similar volcanic rocks are to be seen. But, as might naturally be expected, the volcanoes themselves have long since succumbed to the influence of denudation, leaving us only portions of their outpourings buried up in the hills.

There can be no doubt that the present area of the Grampian Hills was then the site of a consider-

able number of volcanoes, only at a much higher level than their present surface, elevated though that is to the region of the clouds. In fact prolonged denudation has not only removed the volcanoes and their outpourings over this region, but has actually planed away the old mountain surface until all we can see now is a series of detached masses of granite (surrounded by metamorphosed rocks) which were once in a fused and highly heated state far below the surface, and which must have been the subterranean reservoirs from which the volcanoes derived their great supplies of lava and steam. It is indeed difficult to imagine the enormous amount of denudation to which the Highlands of Scotland have been subjected, and to realise that the magnificent range of the Cairngorms (near which the writer is at present) have been for ages worn down till they are now but a remnant of what they once were. And all this by the gentle influence of wind and rain, snow and storm, heat and cold. The words of the poet Hogg—

> "Who was it scooped these stony waves?
> Who scalped the brows of old Cairngorm;
> And dug these ever yawning caves?
> 'Twas I, the Spirit of the Storm"—

express in part an important scientific truth. The above conclusion, based upon the labours of some of our most eminent living geologists, is one of vast importance, and solves many difficulties formerly presented by the study of igneous rocks in the field. It can be exemplified in other regions, such as Wales, Ireland, Cornwall, and Devonshire; and there is no

real difficulty in the difference of appearance and structure between granite on the one hand, and felspathic lavas on the other, because the latter cooled and consolidated rapidly on the surface, while the former did so very slowly and at a great depth below the surface (which implies enormous pressure). And so it is that in traversing some of these mountain districts, when enormous masses of granite and basaltic rocks are found intruding themselves among sedimentary rocks, we are face to face with one of the great mysteries of the present day (but to the geologist an "open secret"), namely the internal anatomy, so to speak, of a volcano. How does it work? Where do the lavas and ashes come from? Such are the questions naturally asked by the visitor to Vesuvius.

Geology can now answer these questions, and presents to our wondering eyes great natural dissections of old volcanoes and volcanic districts in every stage of decay. Now in this case the *past* throws light upon the present. We cannot for ourselves dig away or destroy a modern volcano in order to see what goes on underneath (like children pulling up seeds they have sown to see how they are getting on); but Nature comes to our aid and kindly allows us to look on while she holds a "post-mortem" examination. The scalpel is in her hand. She bids us look into the internal anatomy of what was once a living and active volcano. There we may see the once boiling and seething mass of felspathic rock which fed the Old Red Sandstone volcanoes of this region, now no longer endowed with

life-like power by the force of superheated steam, but lying in deathlike cold and stiffness, with its beautiful crystals of mica and felspar sparkling in the sun. The volcanic fires have died out, to exhibit their powers in other regions ; but the traces of their work are now unmistakable, amongst which we must not forget to reckon the beautiful minerals developed by the action of heat upon the rocks in the regions thus affected. Were it not for past ages of volcanic activity we should have none of the valuable metallic ores (except iron), the gold and silver, or the precious stones of Cornwall, Wales, or Scotland.

We have already pointed out in a previous chapter that one of the chief aims of geological science is to sketch the geography of past ages. The reader may therefore ask if it is possible to indicate in a general way the physical features of the area now known as Great Britain, or of Western Europe, during these times ; to say, for instance, where some of the inland seas were situated, or where open sea lay, if there was open sea anywhere at the time. Now this has been accomplished by an eminent living geologist. To begin with the lakes, Professor Archibald Geikie, who has made a careful study of the Old Red Sandstone in Scotland, has arrived at the conclusion that several distinct lakes existed, the sites of which can even now be traced. The diversities of sediment and of fossils favour the idea that each had a separate existence, with at most only a temporary connection with its neighbour. In his memoir the Professor traces five different lakes, to each of which a name is given to indicate its position. The most

northern and the largest is *Lake Orcadie* on the north side of the Grampians, which probably continued in a north-east direction as far as Norway. The next is *Lake Lorne*, a very small lake in the region of Oban and Mull, marked by the terraced hills of Lorne. The next, going southwards, is a long lake running also north-east and south-west on the south side of the Grampians, *Lake Caledonia*, extending some way into Ireland. In Scotland its site is marked by the widest and central strip of Old Red Sandstone so conspicuous in a geological map. Then lower down still comes *Lake Cheviot*, over the east of Berwickshire and north of Northumberland, including the area of the Cheviot Hills. Lastly, there is the *Welsh Lake*, extending from Shropshire into South Wales. What was the exact nature of the ground between these lakes we may never know ; but it is highly probable that there were mountains, as we have already indicated in the case of the Grampians.

Farther south there was an open sea, extending right into the heart of Europe, in which the rocks known as "Devonian" were deposited. Of these we will speak presently ; but first we must conclude our survey of the Old Red Sandstone with a brief description of the fossils it has yielded.

It will be best to begin, according to the plan already adopted, with vegetable remains, and then take those of the animal kingdom. We have already mentioned the fact that some remains of land plants have been found in British Old Red Sandstone strata; but in America a much more abundant harvest of

fossil plants has been reaped. Principal Dawson of Montreal has found no fewer than 118 species of land-plants, lycopods and ferns being most abundant, and some being tree-ferns. That there were some big trees in the forests of these times is proved by the presence of remains very similar to those so well known from our "Coal-measures" under the names of Lepidodendron and Sigillaria, some of which we will endeavour to describe in a subsequent chapter on the Carboniferous period. Meanwhile, by referring to the illustrations of that chapter the reader may gather a general idea of these plants. But higher forms of vegetable life than these cryptogams have been found, namely a few conifers (which belong to the phanerogams); and from one locality Dr. Dawson secured a fragment of wood belonging to a dicotyledon (like our modern oaks and elms).

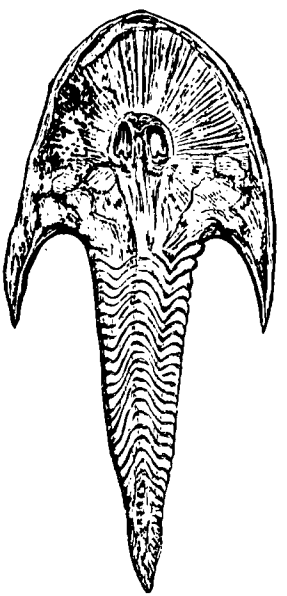
But more than this, we have just a glimpse into the insect life of the Old Red Sandstone forests; for from Devonian strata in New Brunswick several remains of fossil insects have come. Chiefly the wings have been preserved; but these organs show them to have been related to our dragon-flies and may-flies (neuroptera); others are more like our modern centipedes. Lepidoptera (butterflies and moths) probably had not yet come into existence; and as far as the evidence goes there were no honeyed flowers for them to suck, even in the later Carboniferous period. Considering how very ancient the Old Red Sandstone rocks must be, it may well afford the reader some surprise to learn that they

have yielded remains of land-plants and insects, the antiquity of which he will more fully realise after reading the history of the immense pile of subsequently formed rocks, each group with its own peculiar assemblage of fossils. But these facts bid us look farther back still, and encourage the hope that even the Cambrian rocks, when carefully searched in new localities, may yield types of plants and animals which at present we are accustomed to associate only with periods somewhat less ancient; for it is almost incredible that the evolution of plant and animal life could have proceeded at such accelerated speed during the Silurian period that from the humble forms of vegetation found to have existed in Cambrian times, such higher types as the equisetaceæ, lepidodendroids, calamites among the cryptogams, and even cycads and coniferæ among the phanerogams, could have been developed; and yet such is the conclusion forced upon us if we refuse—on the strength of negative evidence only—to believe that these higher types did not exist during Cambrian times.

Passing on to the animal kingdom it only remains to allude to the remarkable lobster-like crustaceans, some of which attained huge proportions, and to the fishes, of which sixty species have been obtained from the north of Scotland. For a full and graphic description of these interesting fossils the reader cannot do better than consult *The Old Red Sandstone* by the late Hugh Miller, whose name will ever be associated with the Old Red Sandstone, and of whose memory Scotchmen and Englishmen alike may well

be proud.[1] To attempt their description would lead us into details which would probably be tedious to the reader. It was Miller who first systematically studied these rocks and assigned them their proper place. In speaking of the fossil fishes which he found in great numbers, he says: "Some sudden catastrophe involved the fish in destruction: the figures are contorted, contracted, curved; the tail in many instances is bent round to the head; the spines stick out; the fins are spread to the full as in fishes that die in convulsions; the Pterichthys (winged fish) shows its arms extended at the stiffest angle, as if prepared for an enemy." In seeking for an explanation of these curious facts, he suggests, amongst other ideas, the exhalation of poisonous vapour from neighbouring volcanoes, by which the waters inhabited by the fish became unfit for their existence. We know how easily and how rapidly the fish in some of our own English streams, by the culpable carelessness and neglect of owners of mines and factories in allowing poisonous refuse to be thrown into streams, are destroyed; and the suggestion seems a reasonable one, for it is difficult to assign any other

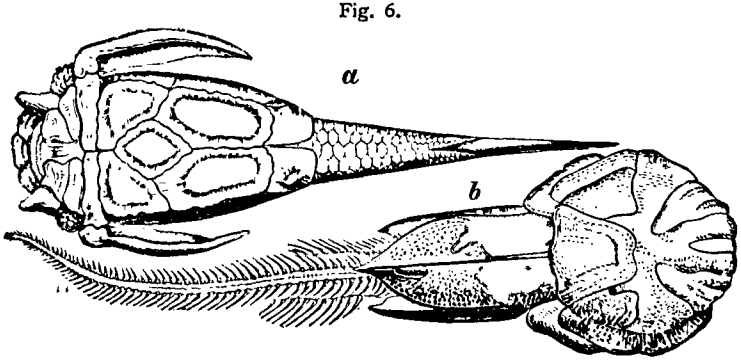
Fig. 5.



Cephalaspis, an Old Red Sandstone Fish.

explanation. The accompanying illustrations (Figs. 5 and 6), will give some idea of three of the commoner ganoid fishes of this period. That the highest known group of fishes, the "mud-fishes" of the present day, containing both gills and lungs, was in existence in these times is testified to by the abundance of the specimens known as Dipterus, which was one of them. Hence we must not be surprised if we find remains of

Fig. 6.



Old Red Sandstone Fishes.

a, Pterichthys. *b*, Coccosteus.

amphibians (the next class above fishes) in the rocks of the succeeding period.

That in an area south of the Old Red Sandstone there was an open sea in these times has already been stated; in that sea the great group of rocks known as Devonian (because exposed in Devonshire) was deposited; and that this sea teemed with living things is obvious to any one who will take the trouble to examine the strata about Torquay or Plymouth. How far the existence of these marine conditions

coincided with those we have described in the north may never be thoroughly determined; but at the same time it seems quite clear that the Devonian rocks are to a large extent intermediate between the Silurian below and the Carboniferous above.

Their fossils bear such a strong *general* resemblance to those about to be mentioned in our next chapter, and this chapter is already so extended, that we will not attempt to describe them, but only ask our readers, should they be travelling to the south-west, not to forget the treasures of the Devonian rocks.

CHAPTER VII

THE MOUNTAIN LIMESTONE

"Yonder is the sea, great and wide,
Wherein are things creeping innumerable,
Both small and great beasts."—PSALM civ.

SOME of the most enjoyable of our English scenery is to be found in those districts where the "Mountain Limestone" comes to the surface; and perhaps none is more distinctive. Choose which locality you will the same general features are always present—bold hills and scars, ravines and gorges, such as those of Clifton, Cheddar, Gordale, or steep cliffs often resounding with the low murmur of falling water. It is a delightful hunting-ground for the fossil collector; while the mineralogist, the botanist, and the entomologist will not come away empty-handed.

Now the "Mountain Limestone" is usually associated with two other formations overlying it; first the "Millstone Grit," and then the great "Coal-measures," which have contributed so largely to our national wealth. Of these we will speak subsequently.

The Limestone is to be found chiefly in South

Wales, the north of England, Scotland, and a large part of Ireland. The reader will remember that some bands of limestone occur in the Silurian rocks, and that in speaking of them we stated that their origin was quite different from that of slates or sandstones, reserving our account of their formation for a future chapter. That account we will now endeavour to give.

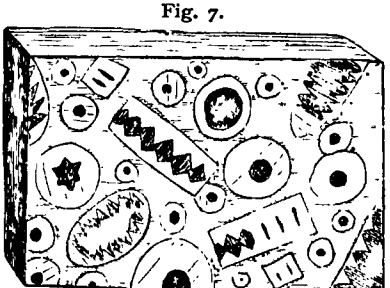
Although we have spoken of this as a great limestone formation (and such it truly is), yet it must not be thought to be composed of nothing but carbonate of lime from top to bottom, for such is not the case. Bands of sandstone and shale occur in parts (and also nodules of chert or flint); but these, except in the north of England and in Scotland, make up a very small part.

Our endeavour throughout this book is to take each rock-formation by itself and to read its history, not after the manner of old-fashioned geologists who racked their brains for explanations of rock-formation which often turned out false—as for instance Werner and his disciples, who said that basalt had been deposited from aqueous solution—but by appealing to the rocks themselves for facts which shall furnish true explanations, always remembering that our conclusions must be confirmed by an appeal to processes now known to be taking place. Microscopists have been busy with this rock, as with others, and the result of the examination of a large number of thin sections, as well as of hand specimens, proves it to be almost entirely made up of many calcareous organisms, together with fragments of such. But

the Mountain Limestone has a thickness of from 3000 to 5000 feet, and therefore it would not be safe to draw conclusions as to its origin from a few specimens. It must be examined right through in order to see if in other parts it may have been differently formed. This has been done, and it is found to have been built up organically in a variety of ways, each of which we will briefly indicate, leaving the reader by personal inspection to verify each fact, and fill in details.

In some parts it is found to be composed of innumerable plates and portions of stems of encrinites or "sea-lilies," like those of Silurian times already mentioned, so that a portion with the surface well weathered presents the appearance of a conglomeration of buttons of all sizes. This is the encrinital limestone, well known in Derbyshire, and often used for chimney-pieces. The slabs when polished show hundreds of stems and plates, which, being cut in every direction, present some very curious shapes (see Fig. 7). Encrinites must therefore be considered as important rock-formers; for they have built up not only a considerable portion of this Carboniferous Limestone, but also have largely helped to form others of different periods, from the Silurian up to the New Red Sandstone.

Fig. 7.



Piece of Limestone showing stems and plates of Encrinites.

It is indeed a startling conclusion that strata of great thickness and of enormous horizontal extent have been built up through the agency of marine animals; for we are not aware, until we study natural history, that the profusion and productiveness of the vegetable world is equalled, if not excelled, by that of the animal world.

We are accustomed to forests and to plains covered with vegetable growth. We cannot help seeing them. But forests of sea-lilies, forests of coral polypes, deep-seated plains where foraminifera lie like the grass which covers the earth, these things are out of sight and hence unknown to most of us. Only naturalists and geologists know that such exist or have existed. There can be no doubt about the meaning of encrinital limestone. It means that where this rock is found there was once a submarine forest of sea-lilies—not plants, as their name suggests, but creatures related to the star-fishes, whose skeleton is formed of articulated calcareous plates arranged in stems with an indefinite number of arms—and that as their fleshy parts decayed after death the plates of which they are composed got separated in most cases, the result of which, continued for thousands of years, produced this rock or "formation." Encrinites are nearly extinct now, for only a few forms have been dredged up from the depths of the Atlantic and Pacific Oceans, but in the past they took a leading place amongst rock-building animals.

We must now pass on to another important class of rock-formers—the reef-building corals. From the Cambrian period until the present time these

beautiful though lowly organised creatures have been silently and steadily at work, rearing great masses of submarine masonry by extracting carbonate of lime from the sea-water and depositing it in their bodies as an internal framework or skeleton. They are not "insects," as is popularly stated, but "polypes," in structure very similar to the well-known "sea-anemones," only with an internal skeleton of lime secreted by certain membranes in such a way that the internal structure of the creature is exactly reproduced in the coral. Now some are single corals, these obviously are not reef-builders; but others are "compound," that is form a colony of polypes all in contact, and in some so closely that a great porous lump of limestone is left behind when the polypes have died, like the well-known "brain-coral," which forms great reefs at the present day. For fuller information on this interesting subject the reader may consult the works of Dana and Charles Darwin; the latter propounded a theory of coral islands which has been generally accepted. He shows how fringing-reefs, barrier-reefs, and atolls represent stages of the same process. Recently, however, Mr. Murray of the *Challenger* Expedition has shown that Darwin's supposition of subsidence as an essential factor in the process is unnecessary.

Large portions of the Carboniferous Limestone are found to be simply buried coral reefs. On weathered surfaces of cliffs and old walls specimens may often be seen standing out an inch or more from the surface, and be traced for long distances. At Clifton Down the fossil dealers sell polished specimens

which are much admired. The best known Carboniferous corals are Lithostrotion, Cyathophyllum, Syringopora, Amplexus, Clisiophyllum, etc.

Fossil collectors will find plenty of the following genera: Productus, Strophomena, Chonetes, Rhynconella, Athyris. But some of the Devonian limestone specimens from Torquay are more beautiful and delicate. Here the limestone is considerably hardened, and forms a favourite marble for the decoration of churches and buildings. Now this kind of change, when carried on to a further stage by the action of heat and pressure long continued, causes a complete obliteration of all organic structure, and we have a crystalline marble such as that used by sculptors. This is no mere theory; for by subjecting chalk to a high temperature in a closed vessel Sir James Hall, a pupil of Hutton, produced a substance exactly like white marble. Hence we may lay it down as an axiom that *all marbles are simply altered limestones.*

The coral structure is so easily obliterated by water-action that, even in modern reefs, it often cannot be detected at a slight depth below the surface. So much for "corals" as rock-formers.

The next class (or rather sub-kingdom) of creatures which may be considered as rock-formers is the mollusca or "shell-fish." These creatures—represented at the present day by our oysters, mussels, cockles, whelks, and other less familiar forms—are mostly marine, although the land and fresh-water snails make a goodly tribe. The testimony of the rocks (and especially of the particular rock we are now considering) is to the effect that these

creatures were just as plentiful in times past as at present, only the families predominating now are not those which predominated formerly. For instance the class known as Brachiopoda, so abundant during the Primary era, is now nearly extinct. However, the result remains the same—that a very fair proportion of the Carboniferous Limestone is made up of molluscous shells and their fragments.

On low shelving coasts exposed to prevailing winds sea-shells are pounded into innumerable fragments, on such a large scale that in some places the beach is composed of nothing else. This is called "shell-sand," and will serve as a modern illustration of rock-formation through the agency of mollusca—for some day it will become buried up under the sea, and in time harden into rock.

The above organisms are the most important found in limestones; but a little practical study of the question in quarries brings to our notice other calcareous remains, such as bones and teeth of fishes, spines and shells of sea-urchins, etc., which are sometimes found in limestones, though not very abundantly. This is all we can learn of limestones with unassisted vision. But here comes to our aid the microscope, and enables us to discover how the fine-grained portions enclosing and surrounding all these remains have been formed. In order to deal with this question more easily we must now turn our attention to a well-known and very fine-grained limestone formation met with over a large part of the country, viz. the Chalk. If we can give a clear account of the formation of this rock, our task is completed.

The origin of chalk was for a long time obscure; but some years ago it happened that, prior to the laying of the Atlantic cable, vessels were sent out to take soundings and report upon the nature of that part of the bed of the Atlantic Ocean on which the cable was about to rest, a true "terra incognita" then, which might reveal—so some thought—steep valleys, ravines, mountains, and other awkward features. But the soundings taken between 1853 and 1857 happily allayed those fears, and indicated only the very gentlest slopes, and a great central plateau admirably suited to the requirements of the case. The average depth was found to be about 1000 fathoms for the plateau, and 23,000 fathoms for the depressions on each side. Samples of the mud lying at the bottom were brought up, to which little importance was attached at the time; but portions were sent to distinguished microscopists for examination. Little was it thought that this dull grey ooze covering a large part of the Atlantic bed would bring a pregnant message from the "depths of the sea," and furnish the answer to a great geological problem. Yet such was the case; for though presenting no definite appearance to the eye, under the microscope it was seen to be chiefly composed of very minute and very lovely little shells, now known as Foraminifera, and much prized by microscopists.

They were originally named from the *foramen*, or hole, connecting the chambers within the shell. They live chiefly at or near the surface, and after the death of the animal the shell slowly sinks

down to the bed of the sea. Now they multiply at so inconceivable a rate that a continuous shower of dead shells seems to be taking place, and the result is the accumulation over vast areas of the Atlantic and Pacific Oceans of a great deposit of "foraminiferal ooze." One form known as Globigerina enormously predominates, so much so that the deposit is generally called "globigerina ooze." Now in these regions far removed from land, where the clear sea-water is free from all sediments, no other process of rock-formation can take place; and therefore the foraminifera have possession of the field. But how does all this explain the origin of chalk? In this way: chalk is found to be almost entirely composed of the very same organisms as the ooze from the Atlantic bed, only in a much less perfect condition. Thus we find that when one agency—that of detritus—fails, Nature has another at hand; for when mud and sand supplies fail the foraminifera come to her aid to carry on the important work of rock-building—one of the chief functions of the ocean. Only we are filled with wonder at the apparent insignificance of the means employed. Poor, frail, invisible little Foraminifer, is it given to you and your countless progeny, so long unknown, uncared for, to build up on your abysmal grave-yard the rocks on which in future ages men shall found their cities, in which shall dwell the kingdoms and democracies of future ages? Is it for you, when we are turned to useless dust, thus to serve mankind? Oh mighty privilege! oh great destiny! And yet ours may be (and we believe will be) greater still—

to lay as firmly and as truly those invisible foundations on which alone communities may rest securely, of Righteousness, Judgment, Peace!

It is necessary, however, to warn the reader not to conclude that chalk and globigerina ooze are identical, a conclusion that seems rather prevalent. All we can say is that there is an interesting connection between them, and that a large proportion, about half perhaps, of the bulk of the chalk is due to foraminifera. Professor Sorby, who has given close attention to the subject, finds, as the result of the examination of many thin sections and samples of chalk, that the remaining portion is due to the decomposition or breaking up of the larger calcareous organisms, such as shells, corals, etc. It has been suggested that a portion at least of the chalk may be due to the chemical precipitation of carbonate of lime from the chalk sea; but the microscope does not reveal any evidence in this direction. Lastly, as an illustration of the breaking-up and comminution of calcareous organisms in the sea, we may mention the well-known fact that coral reefs at the present day suffer great destruction at the hands of the ever-rolling surf—

"The league-long roller thundering on the reef"—

and thus give rise to a deposit of calcareous mud and sand covering the bed of the sea for long distances.

Returning now to the Carboniferous Limestone, the question of its origin may thus be summed up: encrinital plates and fragments furnish the greater part; next in importance are brachiopod molluscous

shells and their fragments; next, foraminifera; and lastly, corals and other organisms. But we have evidence—in the shape of beds of sandstone and shale (mentioned on p. 92)—that the clear water of the Carboniferous sea, in which the limestone grew, was occasionally invaded by suspended mud and sand derived from land, and due to shifting ocean-currents and other causes.

This leads us to the consideration of the physical geography of the British region during these times. By a comparison of the lower Carboniferous rocks over different parts it is possible to arrive at a general conception of the geographical conditions of those times.

Now the principle upon which all conclusions on this subject are based is a very simple one, derived from observation of the manner in which geological deposits are distributed at the present day: first, with regard to the nature of the material; secondly, with regard to the direction in which the strata thin out. On the first point it is obvious that the coarsest and heaviest materials, such as shingle and coarse sand, are deposited in or near the shore, while the lighter and finer materials are carried out some distance into the sea, in fact hundreds of miles. But after a time the supply fails altogether, and we have on the deep ocean-floor an organically-formed deposit taking place, as explained above.

With regard to the second point, it is also obvious that the greatest depth of deposit must be nearest to the source of the sediment, and that a gradual thinning away takes place in the opposite direction.

38662

From this the reader will perceive that it is only necessary to observe the nature and distribution of the lower Carboniferous rocks over the British Isles in order to trace out in a general way the physical geography of our region during those times. Referring the reader to text-books for details on this subject, we need only point out that the limestone is thickest in the northern region of the Pennine Chain, where its thickness is over 4000 feet, and that it thins out very much to the north and south of this area, being at Bristol only 500 feet thick, and in Scotland it has dwindled down to only a few thin bands of limestone. But as the limestone gets thinner the sandstones and shales, etc., get thicker, and in fact replace it. These deposits get thicker to the north and north-west. Now the meaning of these facts is that during lower Carboniferous times the land lay to the north and north-west, while over nearly all the northern half of England (and almost the whole of Ireland) there existed a moderately deep sea, in the clear waters of which the limestone was formed.

Speaking of this very striking change in the character of the lower Carboniferous rocks as they are traced northwards, Professor Geikie says: "It shows that the deeper and clearer water of the Carboniferous sea spread over the site of Yorkshire, Derbyshire, and Lancashire, that land lay to the north, and that while the whole area was undergoing subsidence the maximum movement took place over the area of deeper water. The sediment derived from the north during the time of the Carboniferous

Limestone seems to have sunk to the bottom before it could reach the great basin in which foraminifers, corals, crinoids, and molluscs were building up the thick calcareous deposit. Yet the thin limestone bands which run so persistently among the lower Carboniferous rocks in Scotland prove that there were occasional episodes during which the sediment ceased to arrive, and when the same species of shells, corals, and crinoids spread northwards towards the land, forming for a time over the sea-bottom a continuous sheet of calcareous ooze like that of the deeper water farther south. These intervals of limestone growth no doubt point to times of more rapid submergence, perhaps also to other geographical changes whereby the sediment was for a time prevented from spreading so far" (*Text-Book of Geology*, p. 741).

Coming now to the centre of England, we find along a certain narrow region running east and west the lower Carboniferous rocks almost, or entirely, absent, and "coal-measures resting directly upon the old Silurian rocks." These interesting facts may be interpreted to mean that a thin land-barrier, or perhaps a chain of rocky islands, stretched east and west from North Wales and Shropshire, across the centre of what is now England, and possibly on to Ireland; so that while the limestone was being formed in the seas to the north and south, it died out as it approached this ridge of dry land. Moreover, there is some evidence of volcanic action in this region, a fact which rather tends to confirm such an interpretation.

With regard to the southern half of this Car-

boniferous sea, it also seems probable that a coast-line somewhere over what is now the north-western part of France prevented its further extension south. What were the western boundaries of this sea we cannot say, as the Atlantic covers the rocks; but it probably extended eastwards right up to the Ural mountains.

The land to the north possessed volcanoes, the great activity of which during these times is abundantly proved by the great and numerous basaltic lavas, ashes, and volcanic débris, interstratified with the lower Carboniferous rocks of the south of Scotland. These may be advantageously studied on the hill known as "Arthur's Seat," which even now contains the central orifice of an old volcano, and is "within a mile o' Edinbro' town."

An account of the life of the whole Carboniferous period will be found at the end of the next chapter.

We have now seen what a very important and even stupendous part living organisms of different kinds play in building up great portions of the rocks composing the crust of the earth; and that in this work the smallest creatures play the most important part. That so much of the solid land has once been endowed with the breath of life is a startling fact, and one difficult to realise. To the geologist the words of the poet Montgomery, applied to a mole-hill, come home with a fuller and wider meaning—

> "Tell me, thou dust beneath my feet,
> Thou dust that once had breath—
> Tell me how many mortals meet
> In this small hill of death.

. . . . .

" By wafting winds and flooding rains,
From ocean, earth, and sky,
Collected here the frail remains
Of slumbering millions lie."

CHAPTER VIII

FORESTS OF THE COAL-PERIOD

"Geology is intimately related to almost all the physical sciences, as history is to the moral."—SIR CHARLES LYELL.

COAL is no doubt a very valuable possession to us as a nation, and yet it is with mingled feelings that we reflect on all that coal brings—of thankfulness for cheerful fireside, for the power which carries us by land or water to the pleasant places of the earth or keeps our factory wheels in motion, for light and heat so necessary to our dwellings, and for many useful substances we derive from it; but of sadness at the thought of the dark underground life of the miner, and the dangers he faces; and we think at times of our smoke-plagued cities where the sun seldom shines, and homes of English children reared in dirt and squalor. That is the dark side of the picture; these are some of the shadows cast by our cheerful winter-evening fire. In the meantime it is to be hoped that means may be found of supplying our great towns with motive power derived from those natural sources of wind and water at present

so little valued, but which are destined to do all our heavy work for us. It cannot be that these precious deposits of coal were intended to be used (or rather misused) as they now are. For metallurgical processes, for heating purposes and the manufacture of gas, coal may rightly be used, but not for motive power (or for the blackening of the face of God's earth): and why? Because we have natural forces around us sufficient for all purposes, and far more effective than our dirty and extravagant heat-engines, and to discover how to use them is quite our most immediate duty.

We must now proceed to the interpretation of another chapter of the Earth's autobiography—the story of our coal, recorded in printer's ink (carbon) on many a deeply buried page, and forming a history the interest of which is hardly to be surpassed.

Let the coal speak for itself. And let our first interpreter be the chemist, who will tell us that the chemical composition of coal is very similar to that of trees and plants in general, and that when burnt an incombustible ash is left behind similar to the ash of plants. Also that in comparing the analyses of wood, peat, lignite, and coal the amount of carbon present is found to increase, while the amounts of hydrogen, oxygen, and nitrogen decrease. Now carbon is the most stable element, while the others are easily driven off, as, for instance, when wood is heated in closed vessels till only charcoal is left. Now peat and lignite represent vegetable matter very slightly changed; but the same kind of change carried farther during the lapse of ages would assuredly turn

both into something very like coal. And thus we come at once to the conclusion, presently to be confirmed by stronger evidence, that in coal we have the relics, somewhat decomposed and very much compressed, of a very ancient vegetation. So much for the chemical evidence. Our next interpreters are the miners, who tell us that they frequently find impressions of ferns, reeds, leaves, branches, roots, and sometimes whole stems among the coal-bearing strata —facts which speak for themselves. Such stems are often found at right angles to the seams of coal, that is, in the erect position in which they grew. But we have yet another interpreter—the microscope. Thin slices prepared for microscopic examination frequently reveal structures of an undoubtedly vegetable nature, such as fibres, cells, etc. That coal was once alive in the form of a luxuriant vegetation is thus established on a mass of evidence, the strength of which none would be rash enough to gainsay.

But this at once leads to a series of questions such as these :—Did it grow where we now find it? What kinds of plants existed then, and what animals coexisted with them? Were the conditions of growth similar to those of the present day? We will endeavour to interpret to the reader such answers to these questions as have yet been spelt out by geologists from many a black and deeply-buried page of the record. Facts first, then their interpretation. The facts may be briefly summed up as follows :— Coal is found in seams, varying in thickness from a few inches up to five or six feet or more, and often extending for long distances. Their freedom from

earthy matter or sediment is very remarkable. Under every seam is found a layer of clay or of shale. The strata amongst which the coal-seams are found consist of alternating layers of sandstone and shale (once soft sand and mud). The roots are always found in the "under-clays," and have been traced up into very large stems above them. These facts are of great importance in their bearing upon the modern theory of the formation of coal, and should be carefully noted.

Sir Charles Lyell has thus described a seam of coal in the Parkfield Colliery near Wolverhampton: "In the space of about a quarter of an acre the stumps of no less than thirteen trees with their roots attached appeared, . . . some of them more than 8 feet in circumference. The trunks, broken off close to the root, were lying prostrate in every direction, often crossing each other. One of them measured 15, another 30 feet in length, and others less. They were invariably flattened to the thickness of one or two inches and converted into coal. Their roots formed part of a stratum of coal 10 inches thick, which rested on a layer of clay 2 inches thick; below was a forest resting on a two-foot seam of coal. Five feet below this again was a third forest with large stumps of lepidodendra, calamites, and other trees."

Now who can doubt after reading such evidence, much more after seeing it, as some have, that the conclusion arrived at is a just one, namely that each coal-seam is a buried forest, and grew where we now find it? These buried trunks were once erect, and reared their lofty heads toward the sun like columns

of a great nature-built temple, mightier even than those so wonderfully raised ages ago by the pious Egyptians to their sun-god RA, whom they honoured, but we dishonour, by burning the relics of his sun-raised and fluted vegetable columns in such a manner as to hide his disc with clouds of smoke, to blacken the skies where once he was wont to shine in his strength, and worst of all to darken and degrade the lives of our fellow-creatures. That is our nineteenth century's "sacrifice" to RA!

The student of physical science will not need to be told that when coal is burning it is only giving back the light and heat which it once received from the sun. But to some of our readers this wonderful truth may be new. It is a powerful illustration of the doctrine of the "conservation of energy," which in plain language means that force cannot be destroyed; it is only changed. The following lines express the idea in a popular form:—

> "'Tis the sun's old heat that cooks our meat.
> 'Tis his bottled-up beam that gives us our steam."

It may help the reader to a juster estimate of the truth of this new theory of the formation of coal if we briefly state the old false theory; for as we measure the brightness of a light by the depth of the shadows it casts, so the bright clearness of truth may often be better perceived by contrasting it with the dark shadows and mere semblances of falsehood.

Now the old teaching, in fashion not long ago, was that coal-seams were masses of vegetable matter "deposited" at the bottom of lakes or estuaries, after

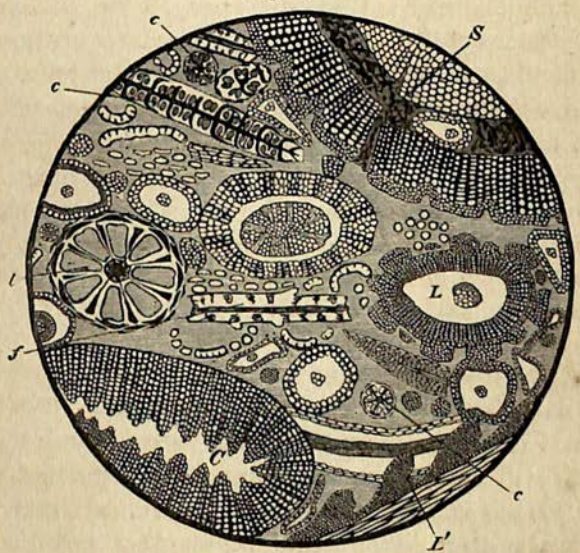
having first been drifted for many miles down rivers, till at last they reached the sea, where they got so soaked with water that in time they sank to the bottom and were buried up with the sand and mud which happened to be forming there. It is a simple, and at first sight rather a taking theory, and is generally known as the "Drift-theory." Those who held this theory based their conclusions on the fact that in certain big rivers great "natural rafts" are sometimes formed (collections of drifting trees and branches) and in time floated out to sea, as described by Lyell. Such phenomena, indeed, may be brought forward to explain small and scattered deposits found in certain rocks of later date than the Carboniferous, but will by no means serve as explanations of those deposits of coal with which we are now dealing. Theories can only be judged by their power to explain the facts, and that theory is accounted the best and most truthful which will explain all the facts. Now if we test the "Drift-theory" in this way we find that it fails lamentably.

Firstly, we must remember that we are dealing with vegetable accumulations of vast extent. Our coal-fields occupy very large areas. For instance the great South Wales or the Lancashire coal-fields occupy thousands of square miles. Nor is this a true estimate of the extent to which the coal-forests must have spread; for it is quite clear that our present coal-fields are but the remnants of much larger deposits which once existed, and it is believed on good authority that a coal-field once covered the whole of Ireland and also the greater part of what

is now England. *Secondly*, the "underclays" found beneath every seam, with their fossilised roots of big trees, often passing up into erect tree-stems, are formidable facts, not exactly in harmony with the "Drift-theory." *Thirdly*, the great purity of the coal-seams and freedom from mud and sand seem to harmonise no better with such a theory; for drifted vegetable matter would be sure to be mixed up with the mud or sand of its final resting-place beneath the sea waves. *Fourthly*, the presence of a great number of the fossilised remains of insects, air-breathing mollusca—such as land snails—and even of reptiles, tell strongly in favour of the idea that the coal-seams grew on land and were quietly buried up where we now find them. Perhaps the strongest evidence is to be found in the footprints of reptiles and little round impressions of drops of rain, eloquent witnesses telling us that showers came then much as they do now; for presently the clouds rolled away, the sun shone out, and before the next flow of water the mud was baked and cracked up, and these precious little markings safely buried up and preserved from harm. *Fifthly*, recent researches with the microscope have shown that some kinds of coal have been largely formed by the gradual accumulations due to showers of little bodies called "spore-cases" from certain kinds of trees, of which more presently (see Fig. 8). Now such a deposit of spore-cases *must* have taken place *on land*, and under the trees from which they came; it is hardly possible that they could have been blown away for some distance and then deposited. Besides, we find

associated with them the cones of fruits which produced them. *Lastly*, it is likely that *some* coal-seams —for they were evidently not all formed quite in the same way—are simply old peat-beds, and grew, just as our peat-beds do at the present day, on low marshy land. These are some of the reasons for the rejection

Fig. 8.



Coal under the microscope, showing sections of stems of ferns (*f*), calamites (*C*), big trees (*S L* and *L'*); *c*, fruit of calamite cut lengthways and across.

of the old theory and the acceptance of the new one, to which the reader will become more and more attached if he studies the facts for himself. One more fact, the "underclays" when analysed are found to be deficient in alkalies, evidently for the simple reason that the plants extracted them for their own

use. Burn the coal to ashes, and you get back these alkalies. (What a pity that the ashes and cinders from our large towns are not sent into the country to be put on the fields!) "Cannel coal" shows no signs of plants, and seems to have been formed by accumulation of vegetable mud in lakes. We must now pass on to the next question, what kinds of plants and animals existed at this period; and having briefly answered that, consider the last question, of the conditions under which coal-forests grew and suffered themselves to be successively buried up.

It is fortunate for the science of geology that coal-seams have so high an economic value to man; for otherwise our knowledge of their fossil contents would be very slight. As it is, the Coal-measures have been more thoroughly searched than any other equivalent set of strata, and consequently our knowledge of their fossil contents is very considerable.

In accordance with our usual plan, we will consider the plants first, and then take a brief survey of the animals of whose existence we have evidence. And here it will be necessary to remind the reader that some plants, containing in their fibres more resin, are better able to withstand the decaying action of water, and so would stand a better chance of being preserved and fossilised, and that therefore it will be only just to assume that many of the less resinous plants of the period have not become known to us, because they failed to be preserved. In this way we have in the known Carboniferous plants a sort of "survival," not in the usual sense of "the fittest" in the struggle for life—though doubtless that same struggle was

taking place even then—but of those most able, in an *after*-death struggle with the elements which make for decay and decomposition, to resist dissolution by water.

As the object of this book is to give a general sketch of each period, "descriptions" such as may be found in the text-books would be out of place. We will therefore first simply state the most typical and important groups of Carboniferous plants. As far as we know at present, they seem to have been ferns—equisetaceæ (or horse-tails) like great reeds, lycopods (or club mosses) of gigantic size, and another set of trees allied to them, the sigillaroids, and lastly coniferous or cone-bearing trees, like our modern pines and cedars. Now all these, except the last, are flowerless plants, called "cryptogams"[1] by the botanists. The conifers, however, have "flowers" of an elementary kind without coloured corollas. It should be mentioned that remains of sea-weeds (algæ) are common in some of the marine strata. The ferns seem to have been very plentiful, and many of them are similar to those living at the present day. The slabs seen in many of our museums, with portions of blackened fronds showing every little mark of their once-green surface, are certainly among the most attractive things to be

[1] All plants are divided into groups as follows :—

I. CRYPTOGAMS—Sea-weeds, lichens, mosses, also lycopods or club-mosses, and equisetaceæ or horse-tails (acrogens).

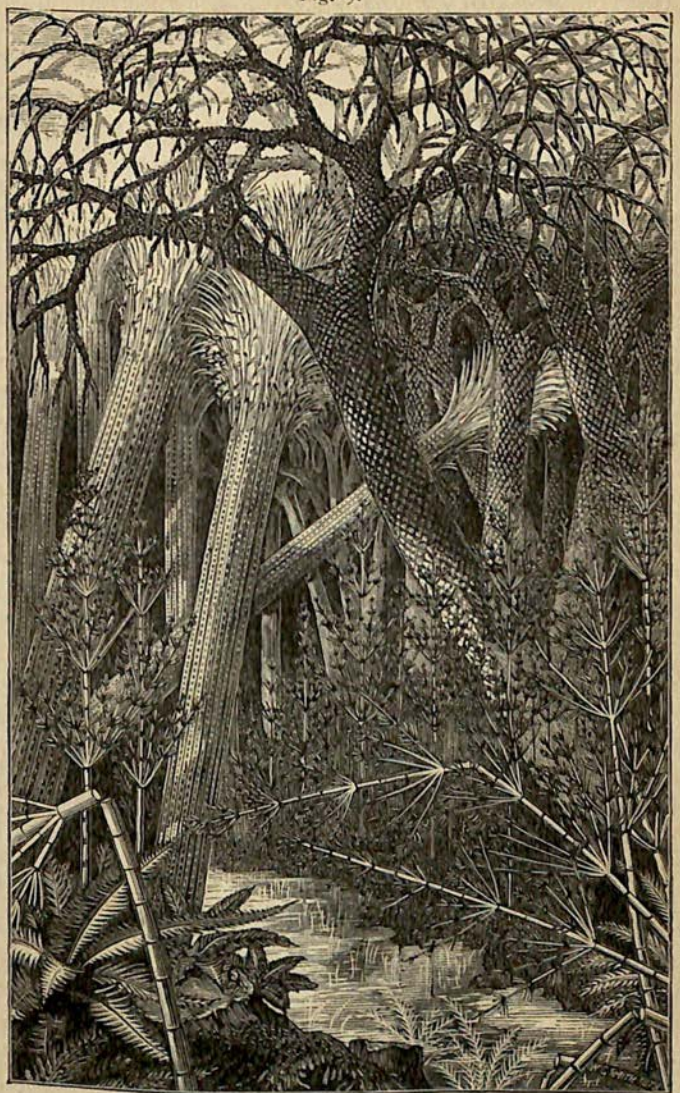
II. PHANEROGAMS—(*a*) *Endogens*, or monocotyledons, *e.g.* grasses, palms, lilies; (*b*) *Exogens*, or dicotyledons, *e.g.* pines, cycads (gymnosperms), ordinary trees and shrubs and most flowering plants (angiosperms).

found in a geological collection. Some, it seems, were "tree-ferns" with tall stems, like those of Brazil.

But on leaving the ferns this similarity to modern forms ceases, at least as regards size. Thus the calamites, whose humble descendants, known as "horse-tails," with their little ribbed and pointed stems, which can be pulled to pieces at the joints, instead of being, as now, a foot or two in height, grew in their "palmy days" of the Carboniferous period to a very much greater height (20 feet or more), and must have been a conspicuous feature of the landscape, growing in dense thickets on low marshy ground.

The great trees whose remains are known under the name of Lepidodendron illustrate the same thing on a greater scale, for they must have reached a height of 50 feet or more, whereas their modern descendants are the little "club-mosses" which doubtless many of our readers have gathered on Snowdon and elsewhere; the largest kind is in New Zealand, and grows to a height of 2 or 3 feet. Incredible at first seems such a downfall! Surely the Carboniferous forests must have been a veritable fairyland, where "mosses" (so-called) grew to the height of an oak or an ash! (see Fig. 9). They were covered all over with little narrow leaves, and we see now on the specimens the little scars marking the point of attachment. Their fruits have been recognised, and are known under the name of Lepidostrobus. One is reminded of the story of the American boasting of the size of the mushrooms produced by his country, where, he said, the trees

Fig. 9.



A Forest of the Coal-period.

Lepidodendron on the right. Sigillaria on the left. Calamites and ferns in foreground.

grew under the mushrooms! Besides the giant club-moss trees, with their curious diagonal markings, there existed equally big trees, the remains of which are known as Sigillaria. Specimens may readily be distinguished by the straight lines running down the bark, and the rows of little marks or leaf-scars between them.

The position of these plants in the vegetable kingdom is a matter of some uncertainty, partly because the determination of a fossilised plant—so different after ages of slow decay from a living one—must always be a difficult task, and partly because its internal structure seems to be somewhat different from that of modern trees. One thing at least the microscope clearly shows, namely that there was once a central pith inside the stem. Specimens have been found showing that, after the main part of the trunk had fallen down, leaving only a stump, the pith decayed and a hollow of bark was left, into which galley-worms, land-snails, and other small creatures found their way; and in some cases these "stools," as they are called, are found to be perfect museums of creatures which got inside and were buried up in mud or sand. In this way too it happens that many internal casts of these plants have been formed.

The greater part of the trees of the coal-forests were the Lepidodendra and the Sigillaria and others of the same type—the first undoubtedly, and the second probably, cryptogamic or flowerless. At the same time genuine flowering trees (phanerogams) with large "woody" stems were in existence; for a

certain number of coniferous plants have been recognised by their concentric woody rings of annual growth, and structures known as "medullary rays." Certain little bodies found buried up with them are believed to have been their fruit. If so, these ancient evergreens produced berries like those of the yew tree, rather than cones like "fir-cones." Little round bodies (known as migonocarpon) are considered to be internal casts of their seed-vessels.

Thus we see that decidedly low types of vegetation prevailed. The Palæozoic era has, not unjustly, been termed "the age of acrogens," or plants which grow by additions made to the summit of the stem. Had man been then existing on this planet and seen coal-forests, he would not have been struck by the variety we notice in our modern forests of temperate latitudes, and what is more serious, he would have had to be contented with a very limited choice of wood for building and other purposes. No oak with which to build ships, no ash, no elm, only "pine," for Lepidodendrons and Sigillarias with their big central pith would have been very useless—unless to form a primitive canoe out of a hollowed trunk. What a poor selection for a carpenter or a shipwright! Indeed the lack of variety noticed on comparing fossil coal plants from all parts of the world—from the Equator to the Arctic Circle—is a very striking fact, though only in harmony with the lowness of type; for great variety is a feature characteristic of high rather than low types, either of plants or animals. Thus we are reminded once more of the great law of upward progress of which we have already spoken, and which

the theory of evolution, as explained by the author of *The Origin of Species*, has so vastly simplified.

Later chapters dealing with the Mesozoic and Cainozoic eras will reveal to us the gradual appearance of higher types of plant life; but at present we must remember we are in the era of acrogens, useful in their age and excellent in their way, but only shadows of good things to come.

The reader will doubtless be curious to know something about the animal life of the Carboniferous period, and especially of the creatures that haunted the coal-forests, and to see how much upward progress seems to have taken place since the time of the Old Red Sandstone.[1] We will therefore pause to take a glimpse of the animals whose remains are preserved to us in those pages of Earth's autobiography known as the Carboniferous Limestone and the Coal-measures. Of the corals we have already spoken; beautiful specimens are to be got from many a deeply buried coral-reef in the west of England, Derbyshire, or West Yorkshire. The encrinites also we have spoken of, as both these groups of animals are important rock-builders. We must next notice one of the Annelides, known as Spirorbis. It is found attached to the fossil stumps and stems of trees, just as at the present day it may be found on our coasts attached to the common sea-weeds. They look like little white specks, but under a lens are seen to be spiral tubes resembling snail shells, though not

[1] The formation known as Millstone Grit comes between the Carboniferous Limestone and the Coal-measures, but contains very few fossils, and is only important as a record of physical conditions leading up to those of the coal-forests.

belonging to the class Mollusca. These little serpulæ tell us that salt, or at least brackish, water, came up to where the coal-forests grew, and that the submergence must have been gradual; for they had time to live and die in the old hollow and decayed stump before they were buried up.

And here we must say farewell to those strange lobster-like monsters, the Eurypterus and its relations, of Silurian and Old Red Sandstone notoriety; for here we find their "last appearance" (if we may borrow a phrase from the advertisers), and that a feeble one. At this stage of the world's history they made their exit, and doubtless to their feebler contemporaries their room was better than their company. The world never tolerates "monsters" for long. And so they played their part. Probably they failed to adapt themselves to the new conditions, and being only "survivals" from previous periods had to retire from the terrestrial drama. But their place was taken by another group of crustaceans which has survived down to the present times, namely the Xiphosura or king-crabs, from the China seas. These creatures may be seen alive and flourishing in the tanks of the Westminster, Brighton, and Crystal Palace Aquaria, with their long tails and great broad shields or "carapaces." But we fear that these most interesting exhibitions have but a poor chance of being appreciated by a public which is more powerfully attracted by acrobatic entertainments, cat-shows and the like.

However, those who find any interest in these pages may gain much help, and perhaps not a little fascination, in watching the living things contained

in the tanks, not only from their graceful movements, strange or beautiful appearance, but from the light they throw upon the fossils found in the rocks. For it cannot be too strongly urged that the best commentary on the dead past is the living present, and that a true knowledge of fossils (now distinguished as the science of palæontology) is only to be gained by a study of living forms of life. It is unfortunate that there has been, and still is, too much tendency to separate, as by a great gulf, the dead from the living, the past from the present forms of life, the result of which is seen in the arrangement of our museums. "Fossils" have too often been left to the attention of geologists not always well acquainted with the structures and habits of living types of plants or animals. The more frequent introduction of fossil specimens side by side with recent types would not only be a material gain to the progress and spread of geological science, but would be a considerable help to students of anatomy and natural history. The tree of life is but a mutilated thing, and half its interest is gone when the dead branches are lopped off.

Another crustacean order, the Trilobites, follows the example of the Eurypterids and departs from the scene at this stage. The fossil forms found in the Coal-measures are small and degraded; evidently this once great and flourishing tribe had already seen its best days, and so its demise seems only fitting. But other humble crustaceans, the little "water-fleas," flourished abundantly, leaving their small bivalve coverings behind in great profusion. And as if to

atone for the loss of the Trilobites, we find here introduced a new crustacean type, the so-called "Decapods," of which our lobsters, shrimps, and crayfish are examples. (Had man existed in the coal period, lobster-sauce would have been a possibility, and he might have found roots to eat—poor substitutes for roast beef and plum-pudding!) They all had long tails; the short-tailed forms (crabs) we shall meet later on. It is curious to find that the forests of the coal period were haunted by some of the pests which are so obnoxious in the present day; for they had scorpions (very like those now living), spiders, cockroaches, crickets, beetles, locusts, centipedes, and white ants, and how many more unpleasant things we know not. Some of these were found by Dr. Dawson, together with bones of amphibians and land-snails, in the sediment filling up the once hollow sigillaria stumps. Perhaps one of the most remarkable things brought to light from these rocks was the wing of a huge "May-fly"; the netted wings must have had an expanse of 7 inches across, and these neuropterous insects must have been very similar in appearance to our dragon-flies.

Passing on to another class, the mollusca, it will be sufficient to notice certain bivalve shells (such as Unio) which seem to indicate the presence of brackish water, as they are not truly marine at the present day. The discovery of the oldest known land-snail (*Pupa vetusta*) is important, and tells us that our present land-snails can boast of a long and proud pedigree. Doubtless they were equally voracious and destructive of young plants in their primeval forest

homes. The beautiful nautilus of which so much has been written is found in the Carboniferous rocks; its first appearance is chronicled in the Silurian rocks. Why this tribe of highly organised mollusca should have survived through such immense periods of time is one of the many insoluble problems presented to the naturalist. The other numerous mollusca of the Carboniferous Limestone we have already referred to in the last chapter. Leaving the mollusca, we must now pass on to the back-boned creatures, or vertebrates. The fishes were numerous throughout this period, and seem to have belonged entirely to the two groups, ganoids and placoids, already noticed in the Silurian and Old Red Sandstone rocks.

The unequally lobed tails still remain. Some of the larger forms had powerful conical teeth; such teeth are usually only possessed by true reptiles. Also it is probable that some of them had lungs as well as gills. Thus we perceive a marked advance upon the older fish type, and an interesting resemblance to some Australian fishes known as "mud-fish." Fish with conical teeth! what a strange fact. It must mean that these fishes were powerful and predaceous in their habits, just as lions are more formidable than sheep. May it not also mean that a progression towards the reptile type was taking place, and conferring on them the *habits and structure* of amphibians like the newts and frogs, and so foreshadowing the approach of the true reptiles which, as we shall see, flourished so abundantly in the Mesozoic era? In the light of modern teaching these are great facts. Now we do actually find in the "Coal-measures"

remains of amphibians still possessing certain affinities with fishes, namely the extinct order of "Labyrinthodonts." Still more interesting, because visible at the present day, are the changes or metamorphoses undergone by frogs. At one stage of their early career they are practically fishes, with gills, etc., but the gills are presently put off, and in time they become true frogs. It certainly looks as if the frogs meant to teach us a little lesson in evolution, and to show how the fish type progressed to that of the amphibian.

NOTE.—The "Amphibia" of naturalists form a class intermediate between fishes and true reptiles (Gr. *Amphi*, both, and *bios*, life). They live the first half of their life as water-breathers and the second half as air-breathers. Imagine a fish with lungs as well as gills, and some kind of limbs for crawling, and you have an amphibian. They invariably possess gills when young, and sometimes throughout life, whereas a true reptile has lungs only. Among our present amphibians some retain the long tail of their youth, like the newts, while others, the frogs and toads, dispense with them after a while. But our Carboniferous forms all resembled the former in retaining the long tail. Many of their skeletons have a decided resemblance to a salamander. The internal structure of their teeth was very complicated, resembling a labyrinth, hence the name (Gr. *labyrinthos*, a labyrinth, and *odous*, a tooth).

CHAPTER IX

A GREAT INTERVAL

"For a thousand years in Thy sight
Are but as yesterday when it is past,
And as a watch in the night."—PSALM XC.

THE condition of the coal-bearing rocks, often greatly disturbed, folded, and worn down, bears no uncertain witness to great changes and disturbances following their deposition or formation, but evidently preceding the quiet period of the New Red Sandstone or Trias (see Fig. 10, p. 138). To use the language of an historian, we have now arrived at a time of disruption and decay, followed, as we shall see in the next chapter, by prolonged rest and reconstruction with a "new order." We might say of that old Palæozoic era, as we turn our gaze to the Mesozoic, that times had greatly changed.

The consideration of these disturbances, and of this wholesale destruction of old strata, may well be considered in a separate chapter. We have arrived at one of those great gaps in the geological record of which mention has already been made; and though at

first sight it might seem that all record of this long interval were hopelessly lost, yet we know that such cannot really be the case, for doubtless rocks were being formed beneath some sea, or seas, even then, and therefore we may hope some day to find strata of intermediate age between those of the Palæozoic and Mesozoic eras. Indeed to some extent those of the Permian and New Red Sandstone present an intermediate state of things, but for all that we must include them in the later era. Moreover, though stratigraphical records are wanting, yet other evidences are not, and we shall find it possible even here to gather up fragments of evidence to read from. All unrecorded periods, alike of fiction, of human history, or of earth-history, have a peculiar interest and importance from the fact of their affording a freer scope for fancy and imagination, and they often result in good by stimulating further search and by teaching the value of little fragments of evidence which otherwise might be left unheeded.

We come now to a great continental period, the beginning of which we have already seen in the Old Red Sandstone. It continued throughout the coal period (although side by side with these continents there existed the Permian and Carboniferous ocean); yet had it not been for the Old Red Sandstone lakes and the coal-forest swamps we should have known nothing of those old land-surfaces. As a rule a great continental surface leaves no stratigraphical records; it is only in seas that such are usually formed, just as a record is now being kept at the bottom of the Atlantic Ocean, while on the great American con-

tinent hardly any geological record is forming. If America were now slowly submerged how little record of its present aspects and contents would be preserved!

It must be borne in mind that two opposite processes take place on continent and ocean beds. On the one we have *de*struction (effected by rain and rivers), on the other *con*struction or rock-building. In other words, the geological record is kept under water. Inland lakes and seas are the exception which proves the rule. We could almost wish it were otherwise, since man is an air-breathing animal and more interested in the life and physical geography of continents than of oceans. However, a few remains of plants and animals from continents do sometimes get preserved in true marine strata, as we have already seen, and hence the sea keeps some slight record even of continental living things.

Before passing on to the consideration of the changes which took place during this revolutionary period of upheaval and destruction, let us pause for a moment to illustrate our meaning by a reference to human history.

We know that periods of national disaster, of lawlessness and disruption, are often left mere blanks in a nation's chronicle: sometimes because all records, whether written or monumental, have perished; sometimes of set purpose, because the task was unpleasant and not conducive to the national dignity. But we do not therefore abandon all hope of partly filling up the gap; for sometimes other nations in happier circumstances give us some information, and

at other times we find, even among scattered fragments and buried débris, much valuable evidence. We all know that during this century much has been learned of the histories of Egypt, Assyria, and Babylon by a diligent search among buried cities; and only lately a new history, that of the powerful Hittite nation, has come to light. One enthusiast considers that he has found the sacred city of Troy; others have found in Central America the relics of a very ancient civilisation. But these cases apply rather to long periods than to intervals; nevertheless they teach us not to be down-hearted gleaners because the harvest-field looks very bare, and encourages us to search diligently, that so we "may come again with joy, and bring our sheaves with us."

As an illustration of such an interval we may mention the long and dark period in Egyptian history between the end of the sixth dynasty and the beginning of the twelfth, that is between the reigns of Queen Nitocris and King Amenemhat I. Of this period Mr. Berkeley says in his little book, *The Pharaohs and their People*: "The last sovereign of the sixth dynasty was a queen named Nitocris. After her death occurs a perfect blank in Egyptian history; not a line of hieroglyphic writing, not a fragment of ruin has survived from this period of darkness and silence. Of the seventh dynasty the very names are lost; of the eighth nothing but the names has been preserved." Now this is very closely analogous to the period of "darkness and silence," of upheaval and disturbance, which followed that quiet period in earth-history known as the Carbon-

iferous; and we would here point out to the reader how invaluable is the habit of seeking help and instruction from other subjects than the particular one he may be specially interested in. The fundamental laws underlying all nature are the same, and so the world is full of analogies and similitudes; the study of one science throws light on another, as for example music on optics. So with histories; the study of individual histories throws much light on human history, and *vice versâ*. Again the lives of children throw light on those of men and women, and politics may often be illustrated from the nursery (if not from the cradle). So it is with earth-history and human history, and with the history of a tribe of animals or plants and that of a tribe or nation of human beings. We might even go farther and speak of the relation between natural law and spiritual or moral law, but this might be considered out of place.

That this interval was a long one there can be no doubt; but of course it is not possible to measure either geological periods or intervals by months and years. "Is it possible," the reader will ask, "to form some idea of its length, even a vague one?" This is possible; and it will be well to pause here to consider *how*. The geologist knows only two time-keeping processes, the one *rock-formation*, the other *rock-destruction*. A third one is sometimes referred to, namely changes in plants and animals; but after all this kind of change concerns the biologist more nearly than the geologist. The biologist has no clock; he takes his time from the geologist. In other words, when passing

from one rock-formation to another a great change in the fossils is noticed ; the lapse of time required for such evolutionary change can only be gauged by the thickness of the strata in which they are found. We have no indication at the present day of the rate at which new species are formed (naturally), whereas we have, as will presently be shown, some index of the rate of rock-destruction, and so of rock-formation.

As the Greeks used to detect "the lazy foot of time" by the slow dropping of water, so the geologist forms a vague measurement of periods and intervals by the work of water, either as a rock-destroyer or a rock-former. This is Mother Earth's "water-clock." In other words, the only two gauges of time recognised by the geologist are: (1) depth of rock worn away or denuded ; (2) depth of rock formed. Now the condition of the water-clock's accuracy as a time-keeper was uniformity of action—that the drops should continue falling at the same rate. So with the geological "water-clock." These two processes of rock-destruction and rock-formation must be supposed to have been continually working with considerable uniformity. This brings us back to the "theory of uniformity" taught by Hutton and Lyell, which we have already endeavoured to explain (Chapter II). The reader will remember that denudation is chiefly effected by "rain and rivers," and that the consequence of such denudation in one place is rock-formation in another, or in other words, that the débris of continents is carried by rivers to the sea to build up new rocks on its bed. Now rivers of course depend for their supply on rainfall ; hence rainfall is

the main factor in denudation. And so we must look upon the rain which comes drop, drop, drop from the clouds as Mother Earth's "water-clock." Geologists believe that on the whole the rainfall has in past periods been pretty much what it is now, though perhaps rather greater during Archæan and Palæozoic times. Hence we consider that we are justified in forming mental conceptions of former periods, or intervals of time, from the two processes above referred to; and we find it possible at least to compare one period with another and to say which was the longest.

Let us examine our "water-clock" a little more closely in order to see, if possible, at what rate it is now working. If we could translate feet of rock worn away, or formed, into years, that would be a most important result. To give a mathematical basis to geology is one of the great problems of this age; how far it will ever be possible we cannot tell; but some small attempts have been made, and their results may prove to be the first-fruits of a goodly harvest. We will therefore briefly indicate what these results are, and how obtained. To begin with rock-destruction: the subject of atmospheric denudation has been mathematically investigated in order to ascertain at what rate a given continent, or portion of a continent, is at present being worn down by rain and rivers. An illustration will help us to understand how such a calculation can be made.

Imagine a large sheet of water, say the Serpentine in Hyde Park, to remain frozen over for a month, and that during that time thousands of people skate upon

it daily, also that no rain or snow fall during that time. When the skaters first came they found a lovely smooth surface of ice like glass. But we know what happens in such a case; it soon gets "cut up" (as skaters say); men are set to work with brooms to sweep up the débris resulting from the cutting action of steel skates. To explain this geologically—the smooth ice-surface is being "denuded" or so worn down. Now suppose all the resulting "snow," as it is called, carefully kept in piles; a large number of heaps would be formed. Let them all be made into one. We have now a given volume of ice-débris formed from a given surface in a given time. Now if that snow were compressed by hydraulic pressure, we could easily measure its true volume *as ice* (for pressure would cause "regelation" and make it into one solid block of ice). Having got the cubic capacity of the ice, and knowing the superficial area of the Serpentine, it would be easy to calculate the depth of ice worn or denuded away from the surface by the continual skating. Thus

$$\frac{\text{volume of ice worn off}}{\text{area of Serpentine}} = \text{depth of ice worn off.}$$

Now something very similar to this has been done for certain well-known areas drained by certain rivers. We will take the area drained by the Mississippi, which geographers call its "basin," for more elaborate and careful measurements have been made on that river than on any other. This area is so many thousand square miles. Now it is clear that all the mud brought down by this great river to the Gulf of

Mexico is derived from the rocks and soil in that area; the next step is to find how much mud, etc., is brought down every year. This is a difficult matter, and can only be done by many measurements of the average velocity of the water, width and depth of the river, and amount of mud contained in one cubic foot of water. Having found the volume of mud, etc., discharged, it is easy to calculate how much the whole surface drained by the Mississippi must have been lowered (on the average) to produce so much mud, namely

$$\frac{\text{volume of mud annually discharged}}{\text{area of the Mississippi basin.}}$$

It is also necessary to allow for the amount of matter dissolved in the water. It was thus found that in one year the whole surface would be lowered only by the $\frac{1}{6000}$th part of a foot, or that it would take 6000 years for the atmospheric influence to wear away an average thickness of one foot from the whole surface. Other rivers have been subjected to similar experiments. Some gave a more, and others a less, rapid rate of denudation; but the above rate is always considered a safe average. Applying this rate to the whole North American continent with its mean height of 748 feet above sea-level (according to Humboldt), it is found that about four and a half million years would be required to wear it all down to the sea-level. The reader will perceive that this is an important result and justifies further hopes. In a former chapter we endeavoured to show how an estimate can be formed of the thickness of strata removed over a given area (Chapter IV). Now this

method of "restoring" old surfaces can be applied to the Carboniferous rocks. It is thus found that in many parts of this country a great depth and extent of Carboniferous rocks must have been denuded away before the advent of the Secondary era. Professor Ramsay has calculated that a covering of rock to the depth of one mile was removed from the surface of the Mendip Hills; and most of this destruction took place during the interval we are now considering. This enables us to form a faint conception of its length. No one has yet attempted to apply a rate of denudation to this case, and so calculate the time required; for indeed the uncertain elements in such a problem are many. The Mississippi rate of 1 foot in 6000 years would not be applicable to this case, being an average for a large area including mountains, valleys, and plains; whereas the Mendip Hills are a small area. If we could find the rates at which some of our present mountainous regions are being worn down and get an average therefrom, it might be justifiable to apply such an average to the case in point.

Passing on to the other process of rock-forming as a measure of time, we must admit that next to nothing has been done. Of course different kinds of rock would be formed at very different rates, and an average would have to be found. One geologist calculates that it took 1000 years to form one seam of coal 3 feet thick. No estimates have been made of the rate of growth of globigerina ooze, or coral reefs, or sandstones and clays.

One cannot help hoping that before long some

attempts may be made. Would not observations of the amount of sediment in sea-water give us some clue to the rate at which finely suspended sand and mud are falling down to the sea-bed? Under these circumstances all we can do is to amuse ourselves by assuming some average and applying it to a group of rocks, or even to the whole stratified series. This playing with averages may be amusing, but we cannot expect to get much result thereby. However, we may mention that Professor Huxley defeated with more or less success an attack on geologists from an eminent physicist, Sir William Thompson, who sought greatly to limit their demands for time by announcing that according to his calculations (based on the sun's cooling) they ought to consider a length of time represented by 100,000,000 of years quite sufficient to allow for the formation of all the stratified rocks. Accepting the challenge, Professor Huxley applied the limit of 100,000,000 years to the 100,000 feet of rock, by which the whole stratified series are often represented, and, by dividing the time by the depth of rock formed, obtained an average rate of formation of $\frac{1}{83}$ inch per annum, or 1 inch in 83 years. Thus we see that at *that rate* 100,000 feet of rock could have been formed in 100,000,000 years, or 1 foot in 996 years. And who would be bold enough to say that the stratified rocks have been formed at a slower rate than this of 1 inch in 83 years, considering that so many of them were deposited in shallow water near coasts?

Now we have to consider what happened after

the coal period. On looking at the Carboniferous rocks in different parts of the country it is quite clear at a glance that they were not allowed to remain peacefully at their native horizontal, but were much upheaved and disturbed, thrown into folds—here an arch or "anticline," there a trough or "syncline." All this disturbance took place *before* the next geological period, when the Permian and New Red Sandstone rocks were formed. In proof of this statement we appeal to the fact that the latter lie *unconformably* in the Carboniferous (*or* Old Red Sandstone) rocks beneath them (see diagram p. 138), evidence which can no more be doubted than that some one this morning put on his coat *after* he had put on his waistcoat. Also we see that the strain caused thereby was often too great for them to bear, so that they cracked and split over and over again.

Take our coal-fields for instance. They are all "synclines," and therefore escaped denudation, while the Mendip Hills and Pennine Chain are broken and worn "anticlines." Over those no Coal-measures are to be seen; they evidently were there once, but have been swept away. In fact nearly all of what is now England was once covered with Coal-measures, and now we have only fragmentary patches left (see Fig. 10). We must therefore think of this long interval as one of immense denudation, accompanied by great earth-movements, whereby the Carboniferous rocks were upheaved, crumpled, and broken. Lines of splitting and displacement are called "faults" by geologists; all our coal-fields show a great number of these "faults"; there are some faults on a grand scale in

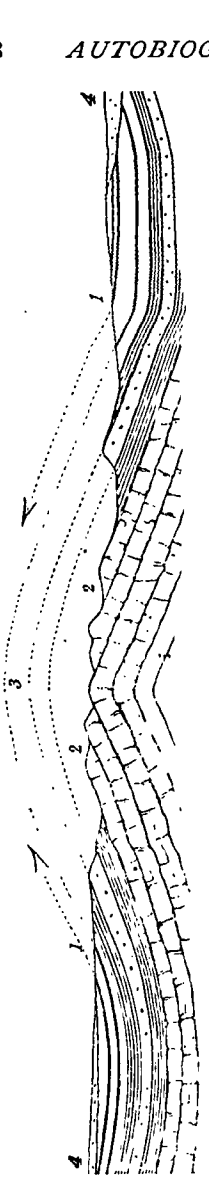


Fig. 10.

Diagram showing the Origin of the Basin-shaped Form of many Coal-fields.

1. Coal-fields showing at the surface in part. 2. Carboniferous Limestone. 3. Anticlinal curve between the two Coal-fields, which were once joined. 4. Permian and New Red strata covering parts of the two basin-shaped Coal-fields.

the north of England. To the above causes we owe the preservation of our coal-fields, and also much of our beautiful scenery; history too has been profoundly affected thereby, and these things are often lost sight of in talking of the "making of England!"

It might seem that the loss of so much valuable coal was a thing to be deplored; but who, if offered the choice, would exchange our Derbyshire and Yorkshire limestone scenery for more coal-fields, more grimy cities, slums, ash-heaps and furnaces? Mr. Ruskin has answered this question in the following striking passage (*Unto this Last*, p. 166): "No amount of ingenuity can ever make iron digestible by the million, nor substitute hydrogen for wine . . . so long as men live by bread the far away valleys must laugh as they are covered

with the gold of God (corn), and the shouts of His happy multitudes ring round the wine-press and the well."

Now the question will naturally arise, How did these movements take place? We do not believe that it was all done suddenly, or in a violent manner. In a former chapter we stated that it is no longer necessary to call in the agency of sudden revolutions and destructions to account for these things, and endeavoured to explain the modern theory of uniformity. Viewed in the light of the reformed teaching, these dislocations and crumplings of the Carboniferous rocks present, on the whole, little or nothing more than the results of such natural and generally quiet processes as are taking place at the present day. We know that within recent (geological) times many parts of the earth's surface have been upraised, as testified by old sea-beaches and terraces now above the sea-level; other parts have as slowly subsided, as the submerged forests prove. We know that earthquakes sometimes cause a local subsidence, and that in active volcanic regions elevation generally takes place. And thus we gain some kind of glimpse into the way in which the upheaval after the coal period took place (see p. 36).

Still at times things may have come to pass rather more rapidly, just as you may slowly bend a stick until it suddenly breaks with a loud snap. Experiments have been made on a small scale to see how much slabs of rock may be bent. It was found that *when under the pressure of an overlying weight* they may be slowly bent to a considerable extent

without breaking. This is an important result, as it is clear that most of the rocks have been bent under the enormous pressure of overlying strata. The Carboniferous Limestone, for instance, had to bear the whole weight of the Millstone Grit and the Coal-measures. We can now understand why it is not more broken up than it is. The experiments also showed that the bending force must be applied slowly.

The times we are now dealing with have left their mark on the face of England and in English history; for it was then that much of our coal-strata were bent down into troughs out of reach of destruction, and that our Mendip Hills were upheaved. At the same time the great Pennine Chain was upheaved. It is clear then that we owe much to this interval, because these physical realities have been important factors in English history.

We know very little about the rate of upheaval of mountains and mountain ranges; but at least it can be proved in some cases that the upheaval was quite gradual. Thus the later Tertiary strata along the south flanks of the Himalayas show that the rivers still run in the same lines that they occupied before the last gigantic upheaval of the chain. In most cases it can be shown that a mountain has not been formed during any one period, but that there were periods of upheaval separated by long periods of repose during which some of the upheaved strata were formed. It is a striking fact that most of the volcanoes of the present day are distributed along our mountain chains. Thus it seems that volcanic action is closely connected with the upheaval of

mountain chains. It is usual to speak of volcanic forces as the cause of the upheaval of mountain chains; but it is much more likely that volcanic phenomena are the consequence of upheaval due to contraction of the earth's crust, and that the lavas flowing from volcanoes are supplied by masses of highly heated rock, which remain solid until by some upheaval of overlying rocks the pressure is lightened, and consequently they at once assume the liquid form and are forced up through the great splits or cracks which are sure to abound in a crumpled and folded mountain chain.

CHAPTER X

THE CHESHIRE SANDSTONES

"The stony rocks are not primæval, but the daughters of Time."
LINNÆUS.

AMONG the many problems presented to us during the course of life, perhaps few recur oftener than the question "where to draw the line"; for it must be drawn somewhere. Now this is just as true in the realm of science as in that of conduct. The chemist, the naturalist, the geologist are alike beset at times with this difficulty of finding where to draw the line. But at least one good resulting from such difficulty is this—that nature thus would teach us that, owing to imperfect knowledge, all our present attempts at classification, arrangement, or grouping, whether of chemical "elements," plants and animals, or strata, are incomplete, and to some extent artificial and temporary.

Now this imperfection is not inaptly illustrated by the group of strata and their fossil contents which we are about to consider; namely those to which the names Permian and New Red Sandstone

(or Trias) have respectively been given. In dealing with the records of nations historians usually take for their "periods" the reigns of kings and queens. This plan, even if somewhat artificial, is at least simple, and avoids the difficulty of marking out others, the limits and duration of which it would be no easy matter to define; for the reign of a sovereign begins at a certain definite point in time, and ends equally definitely. Not so, however, periods of thought action. Who can fix the limits of the "Heroic Age," the "Patriarchal Age," the "Grecian Age," or even the "Age of Iron" and the "Age of Steam"?

Now the subdivision of geological time is accomplished, as already stated, partly by observing the positions of groups of strata relatively to each other, the lowest always being taken as the oldest, and partly also by the comparison of their fossil contents, certain groups of plants and animals having been found to be characteristic of certain strata, because, in accordance with the law of upward progress, definite forms of life flourished at each period. It will thus be seen that in the absence of kings and queens amongst the animal tribes there is considerable difficulty in exactly defining those periods of life which nevertheless in their main outlines stand out clearly enough. Likewise in dealing with the strata themselves, it is often very difficult to say how much must be called by one name (say Cambrian), and how much by another (say Silurian). The fact is they often run into each other by almost insensible gradations, so that one hardly knows "where to

draw the line." If we could follow the plan of the historians so far as to take a certain species, say of trilobite, call him king of the Cambrian period, and say that all rocks containing his remains shall be considered as Cambrian, and then take another species from higher strata and agree that all rocks containing his remains shall be considered as Silurian, we should of course simplify matters greatly; but such a plan would be open to many objections. We must be content with a rough and ready grouping, and if here and there a line of division seems arbitrary we must make the best of it and await further knowledge. After this explanation the author may be forgiven for not assigning a separate chapter to the consideration of the rocks known as Permian (regarded by some as a transition series), but including them with the New Red Sandstone and treating of both together in this chapter. The reasons for so doing will become more apparent as we proceed; and if a precedent be required, it will be sufficient to mention that Professor Sedgwick himself adopted this arrangement.

There was once a splendid city in Egypt known as Memphis. A learned Arab of the Middle Ages has told us of its glories; now all is gone save pyramids and sphinx. But it lives again in another place, its stones once more shelter human beings; for out of its ruins the modern city of Cairo has been built. This use of old building material is one of Nature's devices too. Like the Memphis stones living again with Arabs, our Palæozoic rocks lived again with new forms of life. This is the old story oft

repeated in earth-history. Silurian grits and slates are probably Archæan granites, etc., built up in new ways. From these again some of the Carboniferous and Devonian rocks were derived; and again, the rocks we are about to consider must have been in part derived from Carboniferous and Old Red Sandstone rocks exposed to atmospheric decay.

Thus we read the same cycle of change over and over again. The lofty Alpine peak which seems so immovable and indestructible must as surely be borne down to the sea where it was formed as the rain-clouds of heaven must find their way back to earth and sea from whence they came.

"The hills are shadows, and they flow
From form to form, and nothing stands;
They melt like mists, the solid lands,
Like clouds they shape themselves and go."

Before indicating the manner in which the Permian and Triassic rocks were formed, it will be necessary to state what they are. The first-named take their name from Perm, a province in Russia, where Sir Roderick Murchison, who gave the name, found them extensively developed. The second group were called the New Red Sandstone in opposition to the Old Red Sandstone, which they much resemble, and with which they were formerly confounded. They consist chiefly of sandstones, marls (or fresh-water limestones), conglomerates (with great rounded blocks and pebbles in abundance). But the Permian group contains also an important magnesian limestone with true marine fossils. With this exception these rocks, as known in England, are singularly devoid of fossils. They

are generally of a red colour (due to oxide of iron). In our chapter on the Old Red Sandstone we gave reasons for concluding that the rocks of that name were formed in inland lakes. On somewhat similar grounds it is concluded that the rocks of both the groups we have now to consider were formed in inland lakes or inland seas.

The red colour, scarcity of fossils, numerous ripple-marks, footprints of reptiles, sun-cracks, and impressions of rain-drops, deposits of gypsum, salt-beds, and numerous drifted plant-remains, all point in this direction.

The lower group (Permian) were deposited in isolated basins, in which the water, cut off more or less completely from the sea, underwent concentration, until chemical precipitation took place. In this way the dolomite (a double carbonate of lime and magnesia), rock-salt, and gypsum were formed. These isolated basins must have been the result of local upheavals taking place after the long-continued and enormous subsidence of the coal-forest period. Permian rocks are confined to the northern half of England. In the valley of the Tees they have a thickness of about 600 feet. The dolomitic limestone on the eastern side of the Pennine Chain was formed not organically, like those of the Silurian or Carboniferous rocks, but chemically, by precipitation in a sea highly charged with carbonates of lime and magnesia. We do not deny that the Permian rocks can sometimes be separated by geologists from the New Red Sandstone, and that in some places they lie conformably on the Carboniferous rocks below with-

out a sign of a break or interval between them, or, on the other hand, that many of the Permian plant-remains have a decided resemblance to those of the previous period; *but*, that the two groups are so similar that they are not easily to be separated, and as a general rule run into each other without any break, that they contain remains of plants and animals, many of which differ markedly from those of the preceding period, and show us higher types than any yet found in Carboniferous rocks—these facts seem to compel us to take the two groups together, and to see, even in the Permian, that dawn of a new order of things which is so strikingly exhibited in the rocks of the Mesozoic era.

Turning our attention to the New Red Sandstone or Trias, we find it divided by English geologists into two divisions—the Bunter, or lower member, with its pebble-beds and sandstones (so conspicuous and picturesque at Dawlish), and the Keuper, or upper member, with its sandstones and marls. Their thickness varies considerably, but in Lancashire and West Cheshire may be put down at about 5000 feet. For further particulars we must refer the reader to the text-books.

Let us now see if we cannot form some idea of the conditions under which the Triassic rocks were formed. It should be noticed that they occupy nearly the same sites as the Permian rocks, where those are to be found. But that a certain amount of movement took place before they were formed, and after the establishment of the Permian sea or lake, admits of no doubt. This implies a certain

interval of time, but not such a long one as that we spoke of in the last chapter. Probably there was an upheaval, followed by a subsidence; and perhaps it was a rainless interval, during which any lakes which existed became very much contracted in size for want of rain. Then when the change came and the rainfall greatly increased, the lakes were filled up again and covered large areas. It is possible to trace the sites of three such lakes: one to the south, over Devon and Dorset; one to the north-west in the region of Lancashire and the Lake District; and a third one east of the Pennine Chain, a long narrow lake bounded by mountains.

Mr. Jukes-Brown thus describes the state of things at the time when our lower group, the Permian rocks, were formed: "The open Mediterranean Sea of the Carboniferous period in Europe was converted into a large inland sea, like the Caspian of the present day, surrounded by a rocky and hilly continent, on which grew trees and plants of various kinds. Many of these plants are closely allied to those of the Carboniferous; but species belonging to the yew and fir tribes, which flourish on dry ground, preponderate over the reeds, ferns, and gigantic Lycopodia which flourished in the Coal-measure swamps, while the Sigillaria are not found at all."

Now it would seem that this inland sea was surrounded by mountains and steep slopes; for thus only can we account for the masses of rounded stones of the conglomerates and the "breccias" with their angular fragments. We must suppose, since

stones are only rounded by violent water action, that swift-flowing rivers with considerably inclined courses flowed into this sort of Caspian Sea, bringing mud, sand, and endless pebbles, whose corners had been rubbed off in their way down. But how about the angular fragments? They were probably brought down quickly, when the rivers were more than usually swollen after rains, and so got but little worn. It is well known how among mountains large supplies of stones are broken off by atmospheric influences—heat, cold, and especially frost. The only other supposition would be that they were once a pebble-beach on a sea-shore; this seems unlikely for several reasons. But we ought to mention that Professor Ramsay suggests a glacial origin. In that case they would be "moraines," and the mountain valleys must have been filled by glaciers, which crept down to the lakes bringing débris, like those in Switzerland at the present day. However, it is doubtful, to say the least, whether any true glacial markings or striæ, have been found in these curious Permian conglomerates and breccias.

Returning now to our Triassic Sandstone, we find in its lower portion (the Bunter rocks) a great thickness of pebble-beds and sandstones. It has already been stated that a lake existed over what is now South Devon and Dorset. It would seem, from the pebble-beds and coarse sandstones of Teignmouth and Dawlish, that powerful streams flowed into this lake from the south; for some of the stones probably came from Brittany (so say those who have compared them with rocks there). The key to their

interpretation is to be found in the manner in which torrents from the Alps at the present day bring down vast quantities of detritus—fine in summer, coarse in winter—into the Mediterranean, piling it up into great slanting layers hundreds of feet deep near their mouths. But probably in this case, as in Abyssinia at the present day, it was piled up in the lower part of land-valleys, and not in the waters of the lake. But the Keuper marls and sandstones overlying these coarse deposits were laid down in a more tranquil manner. The marls are believed to have been formed by the accumulation of vast numbers of little calcareous organisms in fresh-water lakes. This would last for a time, and then some sort of change took place so that rivers brought in sand, and thus the Keuper sandstones may have been formed. But the lakes of that time were subject to great variations in volume. When, after long evaporation, the waters became highly charged with saline matters precipitation took place. In this way the salt-beds of Cheshire and Droitwich were formed. At the present day a similar process is taking place in the Dead Sea. We can now clearly see how the sun-cracks, marks of rain-drops, and the reptilian footprints are to be explained. They were formed in soft flats of mud and sand left exposed to the sun's rays as the waters of the lake receded; when, after an interval, swollen rivers filled the lake up again these interesting "footprints on the sands of time" were sealed up. But we need not think of the Keuper sandstones as formed *entirely* under water; for in some places at the present day a vast

extent of loose sand is piled up by wind action. A clever microscopist, the late Mr. Arthur Phillips, after comparing the appearance of Keuper sand-grains under the microscope with those of the Egyptian desert, has concluded that much of the Keuper sandstone had been subjected to wind action; the grains were seen to be worn and rounded in just the same kind of way.

We have now to look at the state of things in the animal and vegetable kingdoms during the period under consideration. To begin with the vegetable kingdom, we need not be surprised to find that in reviewing the fossil plant-remains from the Permian rocks the authorities in this rather abstruse branch of geological science consider that their affinities are with the Carboniferous flora; in fact we may say the Carboniferous flora lived on into the Permian period without undergoing much change. The species are new in nearly every case, but the genera and families nearly the same. For all that we miss certain old friends, such as the sigillaroids; also we meet with conifers producing true cones, and thus differing from their predecessors. As time went on and the New Red Sandstone rocks were formed, the great group of cycads or "false palms" put in an appearance; these we shall find very abundant in the Jurassic and Cretaceous rocks later on. And now not merely a slight, but very considerable, change has taken place; for many old friends are gone. Where are the lepidodendroids and some of the familiar Carboniferous ferns? We must not expect to see them again; for now our flora has a decidedly

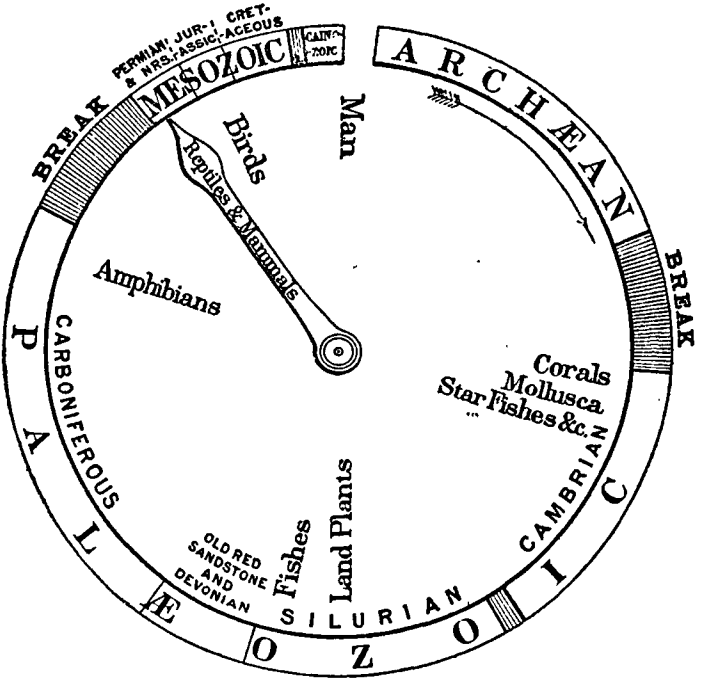
Secondary (or Mesozoic) stamp or "facies." By way of marking the difference between the Primary and Secondary floras, the latter period has been called the "Age of Cycads." On passing to the animal kingdom still greater changes than these are presented to our view. The lower or Permian group contains an assemblage of fossils presenting a general likeness to their predecessors of the Coal-measures; but nevertheless changes of considerable importance had taken place, changes more emphatically marked among the creatures of high organisation. That creatures high up in the scale of life with complex organisation — the "middle and upper classes," so to speak, as opposed to the less susceptible creatures at the lower end of the scale— should undergo more change in the course of geological periods representing long spaces of time is only what might be expected; but that such is actually the case can be demonstrated most clearly by a mass of evidence from the records of the rocks. For example, among the foraminifera of the Chalk are found three genera which have survived to the present time, one of them, Globigerina, being identically the same; and even in older limestones may be found some still living types. But with higher types of life abundant in the Chalk sea time has played sad havoc. The ammonites and belemnites are gone; the ganoid and placoid fishes, so abundant then, are now in the minority; a vast number of strange and mighty reptiles have totally disappeared. We shall not therefore be surprised to find in the period we are now considering a marked

advance upon the amphibian type of the Coal-measures in the presence of true reptiles allied to the modern lizards. There is no satisfactory evidence at present that true reptiles, as distinguished from amphibians, existed when the coal-forests were growing; hence the existence of a higher type in the Permian rocks is a fact of much significance. We seem thus to have found one of those distinct advances in the history of the earth which may well mark an era—the Secondary or Mesozoic era of geologists. Let us not forget what o'clock it is; we are now in Mesozoic times (see Fig. 11).

Thus far then we have passed two very important figures on the geological dial; the first at the word Cambrian, which marked the appearance of the earliest known fossils, and the second at the word Silurian, when we noticed the first appearance of back-boned or vertebrate creatures in the form of fishes. And now we see the hand is pointing to the words reptiles, *and* mammals (see next chapter)—a still higher type. This successive introduction of higher and higher types is one of the most interesting features of the geological record, and is justly appealed to by evolutionists. But it should be borne in mind that geological science is still penetrating more deeply and more thoroughly into the recesses of the past, and that probably future discoveries will push back still farther the times of these first appearances. The accompanying illustration is only a statement of our present knowledge, and must not be taken for more than that. To say that in no part of the world did fishes exist before Silurian

times, or reptiles before Permian times, would be a rash assertion based merely on "negative evidence," and that of a doubtful kind. But in the higher

Fig. 11.



The Geological Clock, showing the order of succession of the different periods, and first appearances of various types of life.

The thickness of the Archæan rocks is unknown, but the relative thicknesses of the other groups are roughly indicated by the length of the arc devoted to each. The shaded portions indicate "breaks" in the record.

group, the New Red Sandstone or Trias, is to be found a much richer collection of organic remains. Here

we meet for the first time the well-known belemnites (popularly called thunderbolts) so frequent in Jurassic and Cretaceous rocks. They were the internal bones of cuttle-fishes. Ammonites also first appear in these rocks, if we except certain Carboniferous species of India. The Muschelkalk limestone of Germany, which is absent in this country, contains a rich marine fauna of corals, echinoderms, encrinites, and mollusca; but on the whole the types are distinctly Mesozoic, and we must now expect to find very few of the Palæozoic genera. It is true that certain strata on the flanks of the Alps known as the St. Cassian and Hallstadt beds contain a remarkable mixture of Palæozoic and Mesozoic mollusca or shell-fish; but this is quite exceptional, and points to a partial survival of old forms in an isolated area.

We must presently leave these humble backboneless creatures in order to say a few words about the labyrinthodonts; but in the meanwhile a few remarks about the fishes will not be out of place. The old ganoid and placoid types still prevailed, the former all having the unequally lobed or "heterocercal" tail. Of the latter the teeth and spines are preserved.

But in the famous Rhætic strata of the Bristol Channel is a well-known bone-bed containing some curious teeth to which Agassiz gave the name Ceratodus (or horn tooth), thus founding the fishy genus Ceratodus on the teeth alone. No other parts of this creature have been found in a fossil state; but this deficiency has been amply made good by the fortunate discovery in Queensland of a fish

possessing identically the same kind of teeth, and known as the Australian mud-fish. From this living Ceratodus much has been learned of its Triassic ancestor, as for instance the use of the teeth and the manner in which they were fixed in the jaw. It feeds on vegetable matters torn off from plants and partially crushed by the undulating surfaces of the back-teeth. This is the only specimen of a living genus founded on a fossil; but what is still more remarkable, the Ceratodus is found to possess lungs as well as gills, like an amphibian. Most fishes possess an organ known as the "swimming-bladder," enabling them to rise or sink in the water. The lungs of Ceratodus and Lepidosiren are modified swimming-bladders. The question will naturally be asked, Are the lungs used? Yes; paradoxical as it may seem, this fish can actually defy all the customs and habits of other fishes and live "out of water." This it does during the hot season, burying itself in a hole in the mud and breathing through two little nasal apertures in the mouth; it then returns to the water and like other fishes gets its oxygen by means of its gills.

The "mud-eel" or Lepidosiren of Africa and America is similar in its habits. These very remarkable fishes are justly regarded as furnishing an interesting link between two well-marked classes, viz. fishes and amphibians. When the opponents of evolution inquire for "missing-links" the geologist can point to these curious mud-fishes. But they are not the only instances of fossil creatures intermediate in character between classes which at the present

day are well defined and sharply separated. Further examples of intermediate types will be brought before the reader in future chapters of this work.

Now the mud-fishes are considered by a high authority to be closely related to the ganoids, and if this be granted, then we may be entitled to look upon that once great and powerful race of fishes—still represented to us by the sturgeon—as ancestors (through the mud-fishes) of the amphibians.

Amphibians, in the form of labyrinthodonts, seem to have been abundant throughout Permian and Triassic times. Their curious hand-like impressions are very numerous; the actual bones much less so, for these rocks are not favourable to the preservation of fossils, being too porous. To such foot-prints the name Cheirotherium was originally given, signifying "hand-beast"; but Professor Owen's name labyrinthodon, describing the peculiar structure of the teeth, has since taken its place. We do not meet with any remains of this order of amphibians in the rocks of subsequent periods, so that it is now quite extinct, but whether they survived the Triassic period we cannot tell; they may have lingered on in some stone region as yet unsearched. However, in the succeeding Jurassic rocks of Europe we find no trace of them.

With regard to the climate of this period, there can be little doubt but that it was warm. We have already pointed out the conditions under which these rocks were formed, conditions most nearly approached in warm countries at the present day. But perhaps the strongest evidence for this conclusion is to be

found in the abundance of reptile life during these times; for reptiles are only abundant in hot climates. To the consideration of the fossil reptiles of the Permian and Trias it will be necessary to devote the following chapter.

CHAPTER XI

NEW PHASES OF LIFE

"The old order changeth, yielding place to new."—TENNYSON.

CONTINUING our search among the records of the Mesozoic era we find remains of a host of reptiles of great diversity, often of stupendous size, and in some cases so unlike any of the present inhabitants of the globe, whether living on land or in the sea, that we might almost fancy ourselves in fairy-land as in imagination we clothe the dry bones with living flesh, and try as far as may be possible to picture them as they really were—walking or crawling on the ground, paddling in the water, or flying in the air.

The creatures of a fertile imagination could scarcely be more strange; and to the student of extinct reptiles the "dragons" of old days are hardly less wonderful than the monsters of Mesozoic times would have appeared to man, had it been permitted to the human race to be their contemporaries. We are reminded of the fairy-land where the Lady Una wandered, the hills of which were the home

"Of dreadful beasts, that, when they drew to hande,
Half-flying and half-floating, in their haste,
Did with their largeness measure o'er much land,
And made wide shadow under bulksome waist,
As mountain doth the valley overcaste;
And trailing scaly tails did rear afore
Bodies all monstrous, horribill and vaste."

It is difficult for us, living in an age of mammals or quadrupeds, and accustomed to the state of things we see around us, in which reptiles play only a subordinate part, to picture to ourselves the life of a continent where they played the chief part. But such was undoubtedly the case on the continental area of the Trias, and continued until the close of the Mesozoic era, which is sometimes called the "Age of Reptiles."

In the present chapter we propose to give a brief account of the fossil reptiles discovered in the Permian and Triassic rocks.

The rocks deposited during the great Mesozoic era—sometimes called "Secondary," as following those formerly called Primary—are divided into three groups as follows:—the Trias, the Jurassic, and the Cretaceous. Each of these groups is of considerable thickness, and comprises a series of members known by separate names, as for instance, the Bath Oolite, the Oxford Clay, or the Chalk. The Jurassic and Cretaceous will be reserved for the two following chapters, and treated of in the same way that we have dealt with other periods.

Now one difficulty which meets us at the outset is due to the fact that a large number of the fossil reptiles of this and subsequent periods were so very

different in character from those living now that, even in cases where the remains are complete and well preserved, naturalists find it no easy matter to assign to them their proper places in the reptile class, and to decide in what tribe they should be included; and thus it has been found necessary to create six new "orders" or tribes for fossil forms, while living reptiles can be arranged under four orders, of which turtles, snakes, lizards, and crocodiles are examples. And this difficulty becomes well-nigh insuperable in cases where the remains are only imperfectly preserved. Still it is hoped that by comparing these ancient life-forms with creatures now living we may be able to present to the reader at least a general idea of their character; and it may be well to point out once more that even "a little knowledge" of natural history, so far from being "a dangerous thing," as we sometimes hear, goes a long way to help the student of geology, and to invest with a greater interest the fossils he meets with in the stratified rocks. Such knowledge is easily obtained in the present day by collecting common objects of the country or sea-shore, by consulting popular works on natural history, and, not least, by visiting museums and zoological gardens.

It will be more convenient, as well as more natural, to consider first of all those types which have not become extinct, since they are more or less familiar to all, and then to pass on to those which we can never expect to see in the flesh, but whose bones have been zealously dug up from Nature's grave-yard, the crust of the earth. Bearing this rule in mind,

we have to ask the question, Were there any turtles or tortoises living in Permian and New Red Sandstone times? To this we can only answer that no actual remains of such creatures have yet been found in the rocks of those periods; but some tracks have been discovered which it is quite possible may have been made by turtles. Next we ask, were there any snakes? To this also we must answer that none have yet been found, and it would seem more than probable that they did not exist, since no remains of such have been met with in the succeeding Jurassic rocks, and only one is known in the yet later Cretaceous, while a fair number are known in the latest era, the Cainozoic or Tertiary. But this apparent absence of two of the living tribes does not hold good in the case of the remaining tribes, represented by lizards and crocodiles, for these were abundant. The earliest known lizard comes from the Permian rocks of Germany and the north of England, to which the name *Protorosaurus* has been given, signifying "first lizard." Though more like lizards than anything else, these creatures have in some points a resemblance to crocodiles; in some respects the living "monitors" of Asia and Africa seem to be nearly related to them. Owen says that "the strength of its neck and head and the sharpness of its teeth enabled it to seize and overcome the struggles of the active fishes of the waters which deposited the old Thuringian copper slates." They were 4 or 5 feet long, and probably partly aquatic in their habits, though the limbs show that they could walk on land. It is perhaps hardly

necessary to remark that the anatomist can draw many important conclusions regarding the habits and capabilities of extinct animals by studying their bones, teeth, and general conformation. An animal in the habit of walking on land must have somewhat stiff and well-set limbs to support its body, while another which inhabits the sea, such as a whale, will have smaller and more pliant limbs, with the bones differently set together, and these will be adapted to the work they have to do—not the support of a heavy body (for the water does that), but its propulsion through the water. So with regard to teeth. Everybody is familiar with the difference between the teeth of a horse, which is a vegetable feeder, and those of a dog or cat, which are carnivorous. Again, all the hoofed quadrupeds are vegetable feeders, while those that are carnivorous have claws, which they use with great effect in seizing their prey. Each part of a skeleton has its tale to tell, and all the various parts work together in perfect harmony. A single tooth and a few bones furnish to a master like Owen or Huxley sufficient material for a forecast of what the animal will be like when a perfect specimen may be found.

In the Trias several other lizards have been discovered. One of these named *Hyperodopedon*, found in Scotland, was about six feet in length, a very much greater size than any modern lizards attain. Still more remarkable is the *Rhynco-saurus*, or "beak-lizard," with a skull like that of a bird, probably without teeth, and having its jaws encased in a sheath like the beak of a turtle. No

wonder such an animal puzzles anatomists. Huxley puts it with the lizards (and so we have good authority for considering it here), but Owen puts it in quite another order, of which we must speak presently. Only parts of the skeleton, the skull, and probably its footprints, are known at present. *Crocodiles*, the remaining order of living reptiles, were very abundant. Well-preserved specimens of these formidable creatures, extracted from the Trias, may be seen in some of our museums with their long jaws and powerful teeth. One of them, Belodon, was even more highly organised than any living crocodile. Doubtless they loved to lie and bask in the sun as crocodiles do now on the banks of the Nile; but probably some lived in the sea, for their remains are found in truly marine strata in Germany.

On the whole their skeletons show that they must have been very similar indeed to modern crocodiles; and it is certainly remarkable that this particular order of reptiles should have suffered so little change in the long succeeding ages, while so many other orders presently to be described (Chapters XIII and XIV) altogether vanished before the advent of the Cainozoic or Tertiary era. Why the powerful tribe or order of Anomodonts, or of Dinosaurs, for instance, should not have been able to continue their existence up to the present day (though it is a matter for congratulation that they did *not*) as well as crocodiles is a mystery we can hardly hope to solve.

These questions, and many others, naturally pre-

sent themselves to the student of the earth's past history, although they cannot be answered. Crocodiles are the giants of modern reptiles, and the nearest approach in size and formidable character to their extinct relations of the reptile class. Their presence amongst us now seems almost like a protest on their part that reptiles were not always in the background, so to speak, and a living witness that their class was once very powerful. It only remains to add that certain of the Triassic crocodiles are very imperfectly known at present, because only fragments have been discovered, and thus there is some uncertainty with regard to their relationship, and it is possible that those forms known as "Thecodonts" may not be crocodiles at all, but dinosaurs.

But now we lose sight of living types and pass on to a brief account of a number of extinct types so novel and strange that, apart from a want of specimens completely preserved (in these rocks), they almost baffle description. Lizards we know, and crocodiles we know; but what are these?—plesiosaurs, anomodonts, dinosaurs?

These are three new orders or tribes which we will endeavour to describe briefly; but the reader must be prepared for surprises. The *Plesiosaurs* first appeared in Triassic strata, and lived all through the Mesozoic era. If a geologist were asked to describe plesiosaurus in two words, he might call it a fish-lizard; but that would hardly do it justice, for it has points of resemblance to other creatures as well as fishes and lizards (see Fig. 12). Baron Cuvier said of this strange creature: "To the head of a lizard it

united the teeth of a crocodile, a neck of enormous length, resembling the body of a serpent, a trunk and tail having the proportions of an ordinary quadruped, the ribs of a cameleon, and the paddles of a whale." For further description we cannot do better than quote Dr. Conybeare: "That it was aquatic is evident from the form of its paddles; that it was marine is almost equally so from the remains with which it is universally associated; that it may have occasionally visited the shore, the resemblance of its extremities to those of turtles may lead us to conjecture. Its movements, however, must have been very awkward on land; and its long neck must have impeded its progress through the water, presenting a striking contrast to the organisation which so admirably fits the Ichthyosaurus to cut through the waves. And again: "That it swam upon or near

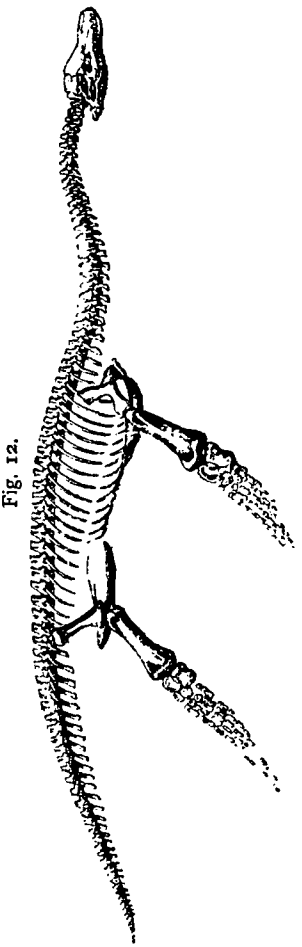


Fig. 12. Skeleton of Plesiosaurus from the Lias.

the surface, arching back its long neck like a swan, and occasionally darting it down at the fish which happened to float within its reach."

Other members of this tribe are Pliosaurus, Notosaurus, Simosaurus, and Neusticosaurus and Placodus; but some of these come very near to the crocodiles. We cannot describe more than one. The Ichthyosaurus above referred to is not known to have existed in New Red Sandstone times, but abounded in the Jurassic period; it will be described in the next chapter. Leaving the plesiosaurs, we must pass on to the next order, the *Anomodonts*, or irregular-toothed animals as the name implies. If a traveller in some unexplored country were to find a reptile with a pair of tusks like a walrus, and without teeth, it would be considered a startling discovery; yet certain strata of this period in Africa, India, and (lately) Scotland have yielded remains of reptiles with curious turtle-like mouths, provided with formidable tusks, to which the name *Dicynodon* (two dog-teeth) has been given. With regard to this creature Professor Owen concludes (from the vertebræ of the backbone) that it was a good swimmer, and probably lived chiefly in the water, but must have come to the surface at times to breathe, for the nostrils prove that. The limbs were somewhat like those of marine turtles. Under the name *Oudenodon* (no tooth) another of these creatures is described by Owen, with a rather similar skull, only without the tusks. The same authority places in this order the curious beak-lizard (Rhyncosaurus) already described with the lizards.

But however surprising it may be to find reptiles with tusks, it is still more surprising to find others which took upon themselves some of the characters and habits of fierce carnivorous quadrupeds of the present day. Thus Professor Owen has obtained from strata in Africa (supposed to be Triassic) the remains of a reptile to which he has given the name Cynodraco, or dog-dragon; and it is not inappropriate, for here we have a reptile with the impertinence—for what else can we call it?—to possess three different kinds of teeth, like a regular carnivorous quadruped—namely incisors, canines, and molars. The canines are long and pointed, with a resemblance to those of the sabre-toothed tiger, now extinct; and besides this, the fore-limbs have a resemblance to those of a carnivorous mammal. This is only one of several called by Owen *Theriodonts*, because their teeth are like those of modern "wild beasts." The plesiosaurs are sometimes called "sea-lizards," or "fish-lizards"; why should we not call these predaceous and precocious reptiles tiger-dragons? We have precious old English names for our wild-flowers and wild animals which are not likely to be exchanged for Latin ones; would it not be possible to find English names for wild animals of past ages? This would be a step towards encouraging the study of geology, especially with young people, and joining past phases of life with present. For indeed the geologist has a "wild beast show" which, if fitly presented to the public, might well attract almost as much attention as the late Wombwell's Menagerie, or even the Zoological Gardens!

It might be mentioned here that our knowledge of the reptiles of the Permian and Triassic period is much less perfect than that of the succeeding Jurassic and Cretaceous periods; and hence it will be possible in the next two chapters to give fuller descriptions, because the specimens generally are less fragmentary and more perfectly preserved. It must also be borne in mind that the above classification of extinct reptiles cannot be regarded by those who made it as final; but it is convenient, and serves to express present knowledge.

The last group of reptiles to be considered in this chapter is the strangest of all, namely the *Dinosaurs*, or, as their name implies, the "terrible lizards." This name has been generally accepted, although Professor Huxley has proposed the name Ornithoscelida (bird-legged), which would make prominent one of their most striking and important characters, namely a strong resemblance to birds of the ostrich tribe (the running birds). Another great authority, Meyer, proposed the name Pachypoda, which means thick-footed. We mention these facts in order to point out at starting the peculiar mixture of characters presented by this great and varied group of reptiles. Thus the first name (Dinosauria), given by Professor Owen, connects them with lizards; the second name (Ornithoscelida) connects them with birds; and the third name (Pachypoda) is suggestive of our modern Pachyderms—the Elephant, Hippopotamus, and Rhinoceros, with their thick heavy feet. It will be best, however, to keep to the first name, the one now generally used. While some of the Dinosaurs

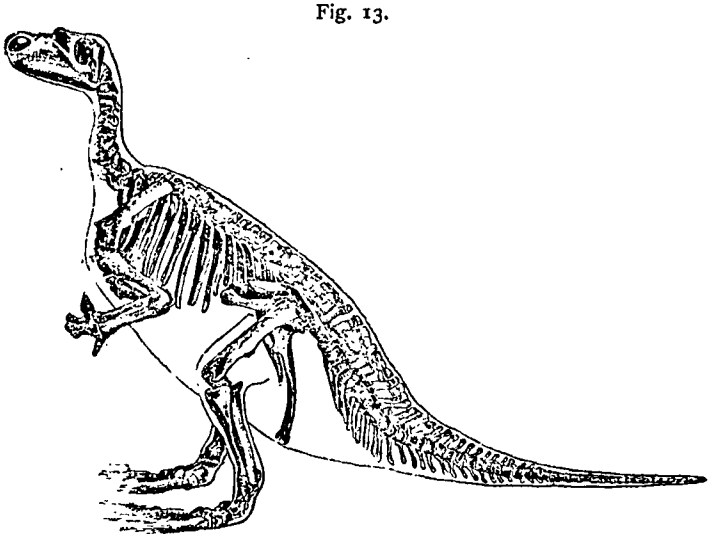
were only 2 feet long and lightly built, others were truly colossal in size and power, thus rivalling our modern whales and elephants. In one of these giant reptiles the upper bone of the hind leg (femur) was $5\frac{1}{2}$ feet long; in another the femur was 6 feet 3 inches long, a great deal bigger than the same bone of an elephant, and the creature itself attained a length of from 80 to 100 feet. The remains of dinosaurs come chiefly from the Jurassic and Cretaceous rocks, and by far the largest number have been found in America; but since a certain number belong to the period we are now considering, it will be necessary at least to introduce them to the reader in this chapter.

The Triassic Dinosaurs were doubtless very numerous; but unfortunately we have to rely mainly upon footprints and fragments of skeletons for a knowledge of them. But with the help of numerous fossil footprints, etc., and a few more or less complete skeletons, some conclusions can be arrived at.

We have already seen that some of the reptiles of this period were so far advanced beyond those of the present day that they had acquired, by a process of evolution, some of the characters and habits of modern carnivorous quadrupeds. But the dinosaurs exhibit a "new departure," for their skeletons show a very marked approach to birds. Without introducing details in proof of this assertion, which would be out of place here, it will be sufficient to refer the reader to one of the best known dinosaurs, Iguanodon (described in Chapter XIV, p. 234). It is probable that many of the Triassic dinosaurs closely resembled

such types as the Iguanodon of the Wealden strata. The restoration here given (Fig. 13) shows the very large hind-limbs and small fore-limbs, the three toes (like a bird's foot), the long neck and small head. That the creature assumed the posture there represented is proved by the gigantic three-toed impressions which it has left behind on some of the

Fig. 13.



Skeleton of a gigantic Dinosaur (Iguanodon) from Wealden Strata.

Wealden strata in Sussex. *Footprints* very similar to these have been discovered in the famous Triassic beds of the Connecticut Valley in America. Indeed the resemblance to bird tracks is in some cases so striking, that serious differences of opinion arose as to whether they were produced by birds or by reptiles; and even now it would seem that

some of them were probably produced by birds, although no remains of such have been discovered here, while further knowledge of the dinosaurs enables us to understand how the large ones were the tracks of gigantic dinosaurs, accustomed to walk on their hind-limbs. Dr. Hitchcock, who has studied this remarkable and varied series of footprints, believes that they were produced not only by birds and reptiles, but also by marsupials, lizards, frogs, turtles, fishes, crustaceans, insects, and worms. Such conclusions prove that there must be a very great variety of tracks; they have been found "in more than twenty places, scattered through an extent of nearly 80 miles from north to south, and are repeated through a succession of beds (strata) attaining at some points a thickness of more than 1000 feet" (Lyell). Besides the tracks numerous little round marks are seen in some places; they are the marks of rain, records of showers which once fell on a soft sandy surface, while the dinosaurs, lizards, and other creatures were hopping or walking about. How strange that all these apparently trivial records should be so beautifully preserved! Doubtless the sun came out as soon as the shower was over, and so the moist soft surface was dried and hardened, so that when the neighbouring inland lake or sea became fuller than usual (perhaps after a rainy season) it spread over its extensive shore, and these now valuable tracks and markings, receiving a coat of sediment, were buried up and preserved for future ages, when the geologist would behold them with delight and interpret to the human race their deep significance.

The Dinosaurs were a great and very varied group of land-reptiles, partly amphibious in their habits, possessing two pairs of limbs fitted for use on *terra firma*, and provided with claws at their extremities, the fore-limbs being generally much smaller than the hind-limbs. In their general structure they are considered to have been intermediate between modern cursorial or running birds, such as the ostrich, and typical reptiles; they may therefore be regarded as "missing-links" between reptiles and birds. It happens that in some cases the hind-limbs are so enormous and so massive as to suggest affinities with modern "pachyderms," such as the elephant; but that does not prove that they show any relationship to such creatures (as has erroneously been supposed). Some were lizard-footed, others bird-footed, with only three or four toes; some were herbivorous in their diet, others carnivorous; some walked or hopped about on land, a few others probably haunted the trees (like birds); some had very solid bones, others had light bones permeated with air-passages (another bird-like feature); some had long necks and small heads, others short necks and large heads. There is one form known with a powerful horn on its skull (like a rhinoceros). Their great difference in size has already been pointed out. Some were provided, like crocodiles, with a defensive armour in the shape of bony plates on the back, or even long and prickly spines; others had no such protection, but were probably very powerful in attack.

These remarks may perhaps serve as a general introduction to the dinosaurs, preparatory to the fuller

descriptions of Jurassic and Cretaceous forms which we shall be able to give in the two following chapters.

The unfortunate scarcity of dinosaurian remains in the Triassic (and perhaps Permian) rocks is matter for regret; but that this great group was then flourishing there can be but little doubt. Their non-preservation is partly due to the porous nature of the Trias, rendering preservation difficult. The dinosaurs show us the reptile class in the height of their power. The evolutionist believes that reptiles and birds were developed from some common form, but whether this wonderful transformation took place actually through the dinosaurs we cannot tell yet; at any rate these creatures mark the highest point in the animal scale attained by reptiles *as such*. After that they began a downward course, and from being "lords of creation" in Mesozoic times they had to be content to take a lower place and make way for a yet higher type—the quadrupeds or mammals which are now at the head of the animal kingdom. Their origin is involved in obscurity. They seem related to crocodiles, but there is no evidence of crocodiles passing into dinosaurs.

Thus geology reveals to us the fact that classes of animals rise and fall, are exalted and then brought low, just as empires among men. It now only remains to show that even in Triassic times the usurpers had appeared on the scene in form of humble little mammals—creatures apparently unable to cope with their rivals of the reptile class, but

destined as ages rolled on to grow in power and strength, and so attain the proud position they now occupy. One cannot help wondering how the victory was accomplished; but they had a more developed brain than the reptiles, and that would give them an immense advantage in the "struggle for existence." Thus it would seem that brains "carried the day," and so mammals now hold the field against their enemies.

The evidence for the existence of these creatures is in the form of some teeth discovered in Jurassic rocks in Germany and England, a complete jawbone (with the teeth) from America, and lately a whole skull from South Africa. Now anatomists can find out a great deal from teeth alone, but with teeth, jawbone, and skull, they are pretty well off; and on this evidence they tell us that the creatures to which these relics once belonged were pouched quadrupeds or marsupials (like the kangaroo), and that the little banded ant-eater of Australia is more nearly related to them than any other living marsupial. To the teeth the name *Microlestes* (or little beast of prey) has been given, to the jawbone the name *Dromatherium* (or nimble beast), and to the skull the name *Tritylodon.* In concluding this chapter it is well to point out that it does not at all follow that the reptiles and mammals therein described were the first of the kind that ever appeared on the earth. On the contrary, it is believed by some of our best naturalists and geologists that reptiles and mammals —and birds also—were already in existence in the Palæozoic era, but not in those parts of the world

which have been explored by the geologist. The reader may therefore safely consider the creatures described in this chapter as immigrants from other regions; "but," as Hugh Miller says, "the night grows dangerous, and these monster-haunted woods were not planted for man. Let us return then to the safer and better furnished world of the present time, and to our secure and quiet homes" (*Lectures on Geology*).

CHAPTER XII

BATH OOLITES

"Slime their material, but the slime was turned
To adamant by their petrific touch.
Frail were their frames, ephemeral their lives,
Their masonry imperishable."

MONTGOMERY.

WE now proceed to the interpretation of another chapter of the Earth's autobiography. The pages on which it is written are perhaps less mutilated and torn away by denudation than those of any previous chapter. Moreover they have not suffered from those metamorphic changes which so seriously affected a large part of the Palæozoic series, thus altering their appearance and at times rendering their interpretation difficult. In other parts of the world Jurassic rocks may have suffered more or less change; but here in England we have them pretty much as they were when first lifted up out of the sea, and also but very little affected by subsequent earth-movements. It is mainly in the sea that Mother Nature keeps her records. When these have been quietly accumulating in her submarine printing-press, where she stamps

her pages with many strange characters — ripple-marks, worm-tracks, sea-weeds, and such like,—then after a time they are heaved up and left to dry and harden while the records of another period similarly grow. In this way she "periodically" issues a chapter of her *Preterita* as time goes on, preferring wisely (like the distinguished author of *Modern Painters*) to do the task herself. It will be necessary to give a few details about the Jurassic rocks before we can attempt to read their history. We will endeavour to do this as briefly as possible.

The British Jurassic rocks form a great series, consisting mainly of clays, sandstones, and limestones, with a maximum thickness of about 4000 feet. They fall into two groups—called respectively the Lias and the Oolites, and each of these in turn has its own subdivisions, some of which are only local. The former comes into the Lower Jurassic group, while the latter is divided into Middle and Upper Jurassic (see list of stratified rocks, p. 28). A glance at the geological map will show that they stretch across England in a varying band running north-east and south-west from the mouth of the Tees to the coast of Dorsetshire. They take their name from the Jura Mountains, where they are well developed. It is a remarkable and significant fact that these rocks consist, roughly speaking, of three great deposits of clay, followed in each case by a limestone formation, with sand and sandstones coming in between.

It was Professor Phillips who pointed out this curious threefold arrangement of clay, sandstone,

and limestone. No less than five repetitions of this remarkable succession have been traced from the top of the Lias to the top of the Portland beds. But omitting the sandstones, we find at the base of the series the Lias, which is mainly a clay formation, succeeded by limestones known as the Inferior Oolite and the Great or Bath Oolite (a valuable "freestone" for building purposes). Then comes the Oxford Clay, over which lies the Coral Rag, another limestone formation largely made up of corals and coral débris. This is in its turn overlaid by the Kimmeridge Clay; then come the Portland and Purbeck limestones. Also we find numerous alternations of clay and limestone on a small scale in the lower Lias and in some parts of the Oolites (without sand between). Is it not probable then that whatever causes contributed to the making of the great alternations just mentioned may have also caused these small alternations? We must consider this question a little later on.

A few words on the external aspects of the Jurassic rocks may not be out of place. We have some very pleasant scenery where they come to the surface, as round Bath and about the Cotswold Hills. Each group of rocks has its own characteristic scenery, and the Jurassic series is no exception to this rule. They do not exhibit the wild and rugged features of the Palæozoic rocks, but broad pasture-lands, smooth green hills, and pleasant vales, with quiet hamlets and meandering streams—no mountain torrents, no crags, no precipices. The clays will be found in the valleys; for, being soft, they were easily worn down, while the limestones, being harder,

suffered less denudation, and consequently stand out as gentle ridges or escarpments. The strip of Jurassic rocks running across England divides the country into two very distinct halves. The country to the west of this line is mostly wild and rugged, the home of the Palæozoic rocks, rich in mineral deposits—tin, copper, lead in Wales and Cornwall; coal and iron in South Wales, Yorkshire, Lancashire, and Durham. And since the Palæozoic rocks are considerably disturbed, and in great part altered by heat and pressure, and moreover since they have been exposed for such long periods of time to the forces of disintegration—heat and cold, rain, rivers, and glaciers—it is not surprising that they present the weather-beaten appearance which so often gives them a charm unpossessed by the rocks of later ages (in Great Britain). But this is not all. It is easy to show that each has had a profound influence on the nation. On which side must we expect to find our great centres of industry, our mining and manufacturing population? Clearly on the side where our coal and iron and other minerals abound. But on the east side of this line we find few centres of industry, and the inhabitants mostly employed in agricultural pursuits; and from these facts follow many consequences, social and intellectual, on which we cannot dwell here.

Before proceeding it may be well to explain the terms Lias and Oolite. The word Lias is a corruption of "layers," a name given to these rocks because they are seen to be largely made up of alternating layers of clay and limestone. The word Oolite refers

to the texture of certain limestones, which are seen on close examination to be made up of little round grains, presenting the appearance of the "hard roe," (or eggs) of a herring, and sometimes they are larger and about the size of peas. The word is formed from two Greek words (*oon*, an egg, and *lithos*, a stone), and so means egg-stone, which is not inappropriate. It should, however, be borne in mind that this structure is not entirely confined to limestones of Jurassic age. It is met with in some parts of the Carboniferous Limestone; but so many of the Jurassic limestones have it, that they deserve to be called "the Oolites." We must remember this when we come to consider how these rocks were formed, regarding it as a little piece of evidence worth a hearing. To the geologist the Oolites are classic ground; for William Smith, "the father of English geology," was the first to trace them over the country and make out their subdivisions. Before his time people had no idea of a definite and regular succession of rocks extending over the country, and capable of being recognised to some extent by mineral character, but more especially—even from one end of the country to the other—by their fossil contents. This discovery of a definite sequence of rocks, each with its own peculiar fossils, was indeed a great discovery, and raised the study of the rocks to the rank of a true science (see Chapter V).

We have spoken of the Lias as mainly a clay formation, and it is; but the middle division has some sandy beds, ironstones, and impure limestones. The ironstones furnish the famous Cleveland iron

ores. Some of the limestones are so thick with shells of Mollusca that we may regard them as old shell-beds.

The famous bone-bed, of which we spoke in the last chapter marks the transition between the New Red Sandstone and Jurassic periods. Many writers include the Rhætic strata, in which it occurs, with the Lias. With regard to the Oolites, Professor Phillips says of them: "In a general point of view the whole is a succession of limestones, Oolitic or shelly, laminated or massive, alternating with clays and sands, locally hardened into sandstones. They cover a wide area, being found in the north of Scotland, and reaching into France on the south. They vary considerably, even in England. Thus the Oolites of Gloucestershire and Wilts will not be found exactly similar in composition to those of Oxfordshire and Northamptonshire; and in tracing them through Rutland and Lincolnshire into Yorkshire very considerable differences will be found. For example, the Great or Bath Oolite, so conspicuous in other parts of England, is entirely absent in Yorkshire, its place being taken by shales and sandstones of estuarine origin, that is, formed near the mouth of a river. Now the Great Oolite being a distinctly marine deposit, this shows that the geographical and other conditions were very different in Yorkshire to what they were farther south.

The Oolites abound in fossils mostly of marine types—corals, sea-urchins, crinoids, shell-fish, and the bones of fishes and reptiles. In many places they are largely made up of shells and shell-

fragments. In some parts we have old coral-reefs. Thus much the eye can easily detect, but looked at more closely they frequently show the Oolitic structure already referred to. The Coral Rag, another limestone above the Oxford Clay, is composed of corals and coral débris, together with shells and echinoderms (sea-urchins), etc.

The Purbeck strata found in Dorset and the Vale of Wardour, are a remarkable group, formed under different conditions to those of the underlying Portland series. They contain some very interesting buried forests (known to geologists as the "dirt-beds," because they contain the old soils in which the forests grew). Most of the Purbeck strata was formed in fresh-water; but there are some estuarine and marine beds, linking them with the Oolites rather than with the Wealden strata, which we will consider as belonging to the Cretaceous period. They also contain the famous "cinder-bed," which is a vast accumulation of oyster shells, 12 feet thick—in fact it is a fossil oyster-bed. They are all of the same species, namely *Ostræa distorta.*

Without attempting further description of the Jurassic rocks, we may now proceed to consider their meaning. Three questions present themselves—(1) *How were these rocks formed?* (2) *What can we gather from them of the climate and geography of the period?* (3) *What types of plants and animals were flourishing then?* To answer the first question briefly would not be easy, because it is clear that these rocks present us with evidences of decidedly varied conditions. Clays, limestones, sands and

shales, buried forests and oyster-beds, obviously could not all have been formed in the same way. So let us first consider the clays, *i.e.* the Lias, Oxford Clay, and Kimmeridge Clay. The Oxford Clay in Dorset is 600 feet thick, and the Kimmeridge Clay in the same county is about 800 feet thick. They all contain fossils of marine types. That settles one question, viz. that they were formed in the sea. Therefore we may at once dismiss any suggestions about lakes or inland seas. Again, they are often laminated, or made up of numerous thin layers, each of which must have been quietly deposited. Clay is a very finely divided material, and only settles down in quiet water (like dust in a room at night). Also they might travel a longer distance from the coast than sand-grains, which are larger, and so would settle down in shallower water nearer the coast. This testifies to an absence of shifting currents and other disturbing influences such as affect the shallower water near a coast. This conclusion is strengthened by the absence of pebbly conglomerates, so characteristic of shore deposits. The fossils also contribute their share of evidence in the same direction. So we have three witnesses, and their witness agrees, namely the lamination, the clay particles themselves, and the fossils. They speak of quiet deposition in sea-water, undisturbed by waves and shifting currents, shoals and sand-banks, and not very near to a shore, *i.e.* in fairly deep water.

All this mud represents so much débris swept off from neighbouring land-surfaces and brought into the Jurassic sea by rivers. What land-surfaces these

were comes under our second question, so we must leave that for the present. Does it seem to the reader that this explanation is hardly sufficient? that some further agency is required to form such widespread deposits as those we are now considering? If so, it may be well to pause and consider what rivers can accomplish at the present time. Careful observations have been made of the amount of mineral matter brought down to the sea by certain rivers. Observations have also been made as to how far from the mouth of a river mud in suspension can be detected. In the case of the Amazon the sea is discoloured for 300 miles from the river's mouth. During the expedition of H.M.S. *Challenger* land-derived materials were brought up by the sounding apparatus at a distance of more than 200 miles from the shore, and at a depth of 1500 fathoms. With regard to the amount of matter brought down by rivers, it must be remembered that some solid matter (such as carbonate of lime and other soluble substances) is brought down in a dissolved state. But taking the dissolved matter, which is small in amount, together with that held in suspension, it was found by Everest that the river Ganges brought down 6,368,077,440 cubic feet of solid matter per annum.

Sir Charles Lyell, after giving other interesting calculations about the work of rivers, says: "It is scarcely possible to present any picture to the mind with which to convey an adequate conception of the mighty scale of this operation, so tranquilly and almost insensibly carried on by the Ganges as it glides through its alluvial plain, even at a distance

of 500 miles from the sea. It may however be stated that if a fleet of more than eighty Indiamen, each freighted with about 1400 tons weight of mud, were to sail down the river every day and every night for four months continuously, they would only transport from the higher country to the sea a mass of solid matter equal to that borne down by the Ganges, even in this part of its course, in the four months of the flood season."

Such a mass of matter would raise the whole surface of Ireland one foot in 144 years. Other interesting observations have been made on the Mississippi and on the Yellow River, with results equally astonishing. Now when we think of these Jurassic clays stretching across England, and of no small thickness, we may not be far wrong in concluding that they were formed by the transporting power of rivers, quite as great as any of those at the present day. It must not be forgotten, however, that ocean currents play an important part in distributing the detritus brought down by rivers.

There is a very interesting point with regard to the way in which some of the fossil remains of the Lias are preserved. Dr. Buckland, speaking of the reptiles of the Lias, says: "Sometimes scarcely a single bone or scale has been removed from the place it occupied during life, and which could not have happened had the uncovered bodies of these saurians been left even for a few hours exposed to putrefaction and to the attacks of fishes and other smaller animals at the bottom of the sea." The skeletons of the ichthyosaurs and plesio-

saurs are frequently found entire, and sometimes the half-digested remains of fishes and reptiles are found within the skeletons, thus indicating the nature of their food. Also the "coprolites" or droppings of these creatures are found perfectly preserved, as if they had been covered up in the mud before they could have had time to decay.

Some of the Cephalopoda tell the same tale; for Dr. Buckland alludes to numerous specimens of cuttle-fishes met with in the Lias, with their ink-bags still distended, containing the ink in a dried state. When mixed with water, the sepia thus preserved made an ink as before, with which Dr. Buckland was able to make a drawing of a specimen, which was thus drawn in its own ink. These facts can only be interpreted to mean that the creatures met with a sudden death, and were quickly buried up. Sir Charles Lyell, endeavouring to explain these facts, mentions that river fish are sometimes stifled by muddy waters during floods, and that the periodical discharges of large bodies of turbid fresh water in the sea may be still more fatal to marine tribes. He goes on to say: "In the *Principles of Geology* I have shown that large quantities of mud and drowned animals have been swept down into the sea by rivers during earthquakes, as in Java in 1699, and that indescribable multitudes of dead fishes have been seen floating on the sea after a discharge of noxious vapours during similar convulsions." But it is a well-known fact that great floods from rivers destroy immense numbers of marine animals. Storms also greatly increase mortality among fishes.

So much for the clays. Let us now turn our attention to the limestones—the Inferior Oolite (with the great or Bath Oolite), the Coral Rag, and the limestones of the Portland and Purbeck groups, at the top of the Jurassic series. We have already alluded (Chapter V) to the organic agencies by which limestone may, in the absence of detrital matter from the land, be slowly built up on the floor of a clear sea. The reader will remember that foraminifera, crinoids, corals, and mollusca were mentioned as the chief rock-forming creatures. Now the crinoids or sea-lilies (with their lovely waving stems and graceful arms) built up a large part of the Carboniferous limestone in Palæozoic times; but in the later periods they ceased to play such an important part. There are, however, some very fine encrinites in the Bradford Clay at the top of the Great Oolite. They seem to have been killed off by a sudden incoming of a mud-bearing current into what was before a clear sea, the bed of which must have been a perfect forest of these lovely creatures, so like plants in form, yet related to star-fishes. Foraminifera are found in these rocks, but they cannot be said to have played any part in forming them. These limestones tell us by their minuter structure, as well as by their fossil contents, that they were chiefly formed by coral and mollusca, together with a vast amount of coral débris, shell-fragments, and calcareous mud.

We must now consider how this can be. Let us see what part corals play at the present time, and how far they are capable of forming large limestone deposits. We shall then be in a much better position to judge.

And perhaps we cannot do better than quote from the very interesting remarks on this subject in Messrs. Jukes and Geikie's *Manual* (now out of print), where the results of observations by Dana and Charles Darwin are clearly stated. After referring to the formation of Atlantic ooze, by foraminifera they proceed to say :—

"In many parts of the inter-tropical regions of the world, however, especially in the Indian and Pacific Oceans, another class of animals, namely the actinozoa, produce still greater effects. When the reefs encircle or front high land, with a navigable water-channel between the land and their outer edges, they are called barrier-reefs by Darwin. The barrier-reef along the north-east coast of Australia is composed of a chain of such masses, and is about 1250 statute miles long, from 10 to 90 miles in width, and rises at its seaward edge from depths which in some places certainly exceed 1800 feet. It may be likened to a great submarine wall or terrace fronting the whole north-east coast of Australia, resting at each end on shallow water, but rising from very great depths about the centre, its upper surface forming a plateau varying from 10 to 30 fathoms in depth, which is studded all over with steep-sided block-like masses that rise up to the level of low water. An idea of its extent may be gained by supposing it transferred to our own part of the world, where it would extend from Brest, across the mouths of the English Channel and Irish Sea, round the west coast of Ireland, to the extreme west point of Iceland, or curve along the shores of Scotland and

the Shetland Islands up to the coast of Norway. In the deep sea around, and in the neighbouring seas from the Torres Strait to the Straits of Malacca, wherever 'bottom' is brought up by the lead, it is found to be very fine, almost impalpable, pale, olive-green mud, which is soluble in dilute hydrochloric acid. This substance when dried would therefore be scarcely different from chalk, though it commonly is of a greener tinge. This fine calcareous mud may be partly derived, like the ooze of the Atlantic, from the calcareous bodies of minute animals; but much of it is doubtless produced from the waste of the coral-reefs themselves. Some fishes, according to Mr. Darwin, browse upon living coral; and all the great Holothuria (trepangs) so abundant in the coral-reefs of the Great Barrier and elsewhere are always full of coral sand. The mere process of digestion, then, carried on by these and other animals, must contribute much impalpable calcareous mud to the adjacent seas."

The wasting of coral-reefs and subsequent spreading out of calcareous débris is a very important geological action, and helps us to understand the great horizontal extent of some limestones. In explanation of this process, a kind of submarine denudation, the same authors say:—

"The outer edge of the Great Barrier (and the windward side of all coral-reefs) is always subject to the battering and pounding action of the most tremendous surf that can be imagined, since the long roll of the ocean-swell falls suddenly upon the upper edge of the great submarine wall, dashing

upon it with almost inconceivable power, roaring over the surface of the reef in huge breakers that are sometimes felt all across it. Although the living coral flourishes most where the surf is heaviest, the greatest masses of mæandrina and porites and other gigantic species live only on the outer edge of the reef; yet if a mass, living or dead, be once detached from the rest, it is soon acted upon by the breakers and ultimately triturated into calcareous sand or mud.

"In addition to the Great Barrier reef just spoken of, all the sea between Australia, New Caledonia, and Lousiade is infested with coral-reefs, so that Flinders called it the 'Coral Sea.' As this space is 1000 miles wide and broad, we have here an area of something like a million of square miles, in which carbonate of lime has been consolidated into great sheets and bank-like masses, which are in some parts at least more than 1000, probably more than 2000, feet in thickness."

Dr. Dana and other observers remark that the older reefs, which have been raised up out of the sea, show very little trace of coralline structure, except on or near the surface, the interior parts being hard and compact, like an old Palæozoic limestone, with rarely a fragment of shell or coral. We have now gained some little insight into the action of corals as rock-formers, and this will help us in our endeavour to picture to ourselves how the Jurassic limestones were formed. But we must not suppose that they were *all* formed by the agency of corals. A very little examination of the rocks themselves will prevent our falling into that mistake. The actions above

described played a very important part, but any one who will go into the quarries may soon satisfy himself that the shells of the Mollusca have also played an important part in the building up of these rocks. In some places we find the rocks almost entirely composed of shells and shell fragments. And doubtless a large amount of calcareous sand and mud will be manufactured by the grinding power of a surf on a shelly beach. The echinoderms or sea-urchins were very numerous in the Jurassic sea, and their broken shells would contribute to the formation of shelly limestone. The sands which occur in various parts of the series were doubtless formed very much in the same way as sand forms in the sea at the present day, here and there as sand-banks, varying their depth and position with the ever-shifting currents of a shallow sea—for sand is not a deep-water formation, because sand-grains do not travel far out to sea.

A large part of the limestones is Oolitic, and the origin of this curious structure already referred to (p. 181) has been the subject of much thought. How have these little round grains been formed? is a question that naturally arises. Some think that the lime was precipitated from the sea-water and formed layer by layer round some little nucleus, which is generally found under the microscope to be a fragment of shell or a grain of sand. This seems a natural explanation, and would testify to the existence of a shallow and warm sea rather highly charged with dissolved lime. But it may be that they were formed somewhat after the manner of a snowball

rolled in the snow—by the rolling of little particles on a floor of calcareous mud. They would thus gather one coating of lime after another, and the rolling might be kept up by wave and current action. The same thing has been noticed in the boilers of steam-engines (the water being charged with more or less lime), and in the stream of the Carlsbad waters. Some recent researches, however, seem to show that probably the Oolitic grains have an entirely organic origin and are the work of minute entomostraca.[1]

We have already mentioned the absence of the Great Oolite in Yorkshire. Estuarine conditions prevailed there, and the strata give evidence of the existence of a true coal-field. Vast quantities of sediment were brought down from the land near and deposited between the other exclusively marine strata. We have also evidence of fresh-water conditions in the Purbeck strata. They contain some very interesting fresh-water limestones, formed almost entirely of fresh-water snail-shells (Paludina). When polished they are known as Purbeck marble, the little shells being plainly visible. These strata also contain the dirt-beds already alluded to, proving that land-surfaces there existed on which forests grew. Taking the Jurassic series as a whole, and excepting these Purbeck beds, it is seen that on tracing them northwards they become estuarine and give other evidences of the nearness of land; whereas on tracing them southwards we find evidences of deeper water

[1] Swarms of minute crustaceans, such as cypris (water-flea) are also found in these limestones.

in the thick limestone deposits. Following then still farther south, up to the Jura Mountains, we find them to be almost entirely calcareous. And so we can safely conclude that the deeper water lay in that direction.

Before passing on to consider our second question concerning the geography of this period, we must try and see if we can understand the causes of the great alternations of clay and limestone, or clays, sand, and limestones which are so remarkable a feature of the Jurassic rocks. These facts must have an important meaning could we but fully interpret them, but unfortunately our knowledge of the conditions of rock-formation in the sea at the present day is still so limited that some questions of this sort can only be partially answered.

How are we to account for these somewhat sudden changes from clay to limestone, *e.g.* from Oxford Clay to Coral Rag? Sir Charles Lyell suggests that the great ocean currents which distributed the mud were changed in direction, and so the mud was brought down to another region; or that perhaps the land supplying the mud was depressed and submerged. The result of this would be that the water would become clear, and therefore fit for the growth of corals and coral-reefs, and limestone might be formed instead. Another authority, Dr. A. Geikie, thinks that the facts may be explained by prolonged but intermittent subsidence, the limestones forming during prolonged pauses when the sea would be getting gradually shallower. Others think that the limestones prove temporary

depression and recession of the coast-lines, but not necessarily a deep sea, while the sandstones indicate elevation. To the author such up and down movements seem rather incredible; and he is more inclined to the idea of prolonged but intermittent subsidence.

We mentioned the frequent layers of clay and limestone in the Lower Lias. These are far from easy to explain. The limestones are impure and rather concretionary, suggesting the idea that they may have subsequently separated themselves out from a mixture of muddy and calcareous sediments, the latter perhaps being the result of the wasting of distant coral-reefs. The author has seen no satisfactory explanation, and only mentions this as a suggestion.

If they are due to shifting currents in the sea, then perhaps the greater alternations of clay and limestone in the Oolites may be due to the same cause. It is to be hoped that before long further light may be thrown upon this question.

We have now to consider briefly our second question, the geography and climate of the period.

On comparing the Lias with the New Red Sandstone below, it is pretty clear that a general submergence followed the Triassic period; the great lakes and inland seas then existing became submerged, and were turned into the sea and bays in which the Lias strata were deposited. A large number of the creatures of the latter period were unable to withstand the altered conditions, and succumbed to the change. Their remains are found in the Rhætic bone-

bed. It was a rapid change, and by the time of the Lower Lias the water was deep enough for the Cephalopoda (ammonites and belemnites) to appear. During Lias times the sea covered all the central and southern parts of England. There was, however, a large area of land to the east of our islands. There was land also in the west. Probably it was continuous from the north of France, through Cornwall, Devon, Wales, and Ireland. There was land also over nearly the whole of Scotland, and in the north-west of England. It seems to have come down as far south as Derbyshire.

A very interesting series of fossil insects—beetles, May-flies, grasshoppers, etc.—have been found in the Lias of England. They are closely allied to living species, and indicate a decidedly temperate climate, while the general flora and fauna of the Lias indicates a warm climate. But there is reason to believe that the mountains of Wales were then much higher than they are now, and that these insects came from that region, where the climate would be cooler, and that they were washed down by flooded streams from these higher lands, and so buried up with other creatures that enjoyed a warmer climate. Professor Ansted believes that the geographical conditions of the Liassic period were similar to those now prevailing on the eastern shore of Asia, where we have big rivers running over extensive flats and pouring their waters into a sheltered portion of the ocean. Dartmoor, Wales, and Cumberland were probably islands surrounded by the warm waters of the Lias sea, a sea containing abundance of marine life.

Passing on to the Lower Oolite or Middle Jurassic times, we find evidence of an open sea of moderate depth in the south of England, with at one time coral banks, at other times rivers coming in. Farther north many rivers flowed in, and they brought down sand, silt, and the débris of plants. Evidently a large continent was near, which probably lay to the east and extended all the way to the Scandinavian Mountains. And this area remained throughout the early part of the Mesozoic era.

In the sea of this period flourished an immense number of marine creatures, 1700 species being already known. Magnificent ferns and cycads grew on the neighbouring land, many specimens of which were brought down to the sea and buried up in these rocks. On the higher ground coniferous trees flourished. The plants of the land and the creatures of the sea all indicate a warm climate. Huge dinosaurian reptiles existed on the land, while some wonderful flying reptiles, known as pterodactyls (see next chapter) traversed the air. There were also some marsupials, but we must defer our account of these creatures to another chapter. It would be difficult to fix anything like a graphic account of the sea and land of the Middle Jurassic period, for they can only be dimly discerned by the aid of the imagination; but if we can point to any particular region of the earth that seems to bear a close resemblance we shall gain a much clearer idea of the conditions of the period. Now it would seem that Australia exhibits at the present day a near approach to these conditions—including its neighbouring islands.

Many of the Jurassic types still survive there. The indigenous mammals are all marsupials; the plants include ferns, cycads, and araucarian pines; coral-reefs in abundance fringe the north-eastern shore; and many of the fish and mollusca living in those seas are very similar to the Jurassic types. But others have disappeared. The strange reptiles from the land, and the ammonites and belemnites from the sea, have all passed away in the lapse of time. Towards the end of the Jurassic period a large part of the sea was raised into dry land. What sea was left had narrow limits; and over the south of England there must have been an estuarine lagoon in which the Purbeck strata were deposited.

We have now considered the first two questions, namely the origin of the Jurassic rocks and the geographical and other conditions of the period. To the consideration of the prevailing types of life we must devote our next chapter.

CHAPTER XIII

AN AGE OF REPTILES

"The Egyptians, it is true, had taught, and the Stoics had repeated, that the earth had once given birth to some monstrous animals which existed no longer."—SIR CHARLES LYELL.

THE forms of life which flourished during the deposition of the Jurassic rocks, as known by their fossil remains, are the subject of the present chapter. We propose to dwell somewhat briefly on the lower forms, some of which have already been referred to as taking part in the formation of the limestones, and to devote more attention to the higher types, the reptiles and mammals, to which the reader was introduced in Chapter XI.

We have already spoken of the existence of land-surfaces near the Jurassic sea. These were covered with a luxurious vegetation, numerous specimens of which were brought down to the sea and there buried up. Such remains afford us a fair idea of the general character of the Jurassic flora. Ferns, cycads, and conifers were the prevailing forms of vegetation. The horse-tails (Equisetum) noticed in

the Coal period and in the Trias were still abundant. Thus we see that there was still a strong resemblance to the Triassic flora. The cycads or "false-palms" are the most marked feature. This great group of plants, so characteristic of the Mesozoic era, is nearly related to the conifers, and seems to have begun its existence in the Coal-measure period. The cycads of the present day are small palm-like trees or shrubs, with unbranched cylindrical stems, marked with leaf-scars. The short stem bears a crown of feathery fronds. They are only found in warm climates.

The Mesozoic era has often been named the "Age of Cycads." Ferns were very abundant, and the conifers were of various forms more or less allied to the araucarian pines of the present day.

Passing on to the animal life of the period, we find that the Jurassic sea was teeming with life of all kinds. The lands also were peopled with many strange forms, from insects flitting through the air to gigantic reptiles haunting the open country or creeping amongst the vegetable growth of forest or swamp. It is perhaps needless to remark that some rocks are very much more favourable to the preservation of organic remains than others. Now the clays and limestones of the Jurassic period were well suited to preserve the remains of plants and animals. In some cases it is almost startling to see how perfect the preservation is, shells of ammonites retaining the original nacreous lustre, and skeletons of fish or reptile are found with every bone in its place. Beginning with the lowest forms of life, we find foraminifera, sponges

and corals all abounding, the latter more like the madrepores (brain-coral) of the present day, Silurian and Carboniferous types having mostly died out. Star-fishes and encrinites were also abundant. Sea-urchins (echinoderms) also flourished vigorously. Passing on to the crustaceans, we find numerous fossils of crabs, lobsters, and shrimps. Very fine specimens of these creatures are found in the famous lithographic stone of Solenhofen, Bavaria, which is a very fine-grained limestone containing a large number of fossils in a wonderful state of preservation. It is used for lithographic printing, and we might almost say that many of the specimens are lithographed on it, so delicate are some of the impressions it has preserved. Dragon-flies' wings, impressions of medusæ (jelly-fish), and the soft arms and tentacles of cuttle-fishes—all these, and many other things which delight the eye of the geologist, are found there. Specimens may be seen in the new Natural History Museum at South Kensington.

Numerous insects have been obtained from the Lias and Oolites. Mr. Brodie found in Gloucestershire Lias numerous wing-cases of beetles, with some nearly entire specimens, of which even the eyes were preserved. The Lias has also yielded remains of grasshoppers, dragon-flies, and May-flies. Fossil spiders have been found in the Oolites, also centipeds. The Purbeck strata yielded remains of beetles, locusts, lice, May-flies, gnats (or creatures very similar); they were probably blown off the adjacent land. The oldest fossil butterfly is found in the Stonesfield Slate, at the base of the Great Oolite.

We now pass on to the Mollusca, commonly called shell-fish. Naturalists divide them into seven classes, each more highly organised than the last. The first is the Polyzoa, of which "sea-mats" and "lace-coral" are examples. Specimens of these curious compound creatures are found in the Oolitic strata. The next class (omitting the Tunicata) is the Brachiopoda, and of much more importance. They abounded in Jurassic seas. We first noticed them in the Cambrian rocks. They were most plentiful during the succeeding Silurian, Devonian, and Carboniferous periods, less numerous during the Mesozoic era, and still less so during the Cainozoic or Tertiary. Only a few lived on to the present day. Lamellibranchs, represented at the present day by oysters and mussels, etc., also thrived vigorously. Ostræa is an abundant genus, and tells off many an oyster-bed. Then come the Gastropods, of which snails and slugs are examples. The Jurassic forms show a nearer approach to modern types, and we miss many of the Palæozoic genera, although pleurotomaria lived on. Some Pteropods are found in these rocks. But the Cephalopods are the most interesting and wonderful of the Mollusca. At the present day this class is but feebly represented by the nautilus and some cuttle-fishes and squids. But during this and the succeeding Cretaceous period many forms now lost flourished in great abundance. We will say a few words about those known as "Ammonites," and "Belemnites." The ammonite was a creature living like the nautilus in a coiled-up shell divided into compartments, in the

last of which the creature lived. They are found of all sizes, from little ones no larger than a threepenny piece to monsters nearly as big as a cart-wheel.

The partitions (septa) between the air-chambers frequently had very beautiful foliated edges (sutures) showing on the outside of the shell. The varieties are nearly endless; 266 species are peculiar to the Lias of Europe, while from Jurassic and Cretaceous rocks together 600 species are known. It is a remarkable fact about these ammonites that in the Lias particular species are confined to certain definite "horizons" (or levels); and on this principle the Lias has been subdivided into a number of zones, each known by a certain species of ammonite. Thus we have at the base a zone of *Ammonites planorbis*, then a zone of *Ammonites angulatus*, and so on. We will not attempt any explanation of this remarkable fact, but we may regard it as a special case of the principle already explained (Chapter V) that each group of rocks is known by its characteristic fossils. The *Belemnite* was a cuttle-fish, with a long pointed internal bone; it was provided with an ink-bag, and so could retreat under cover of a dark cloud of sepia, as modern cuttle-fishes are known to do. A good deal can be gathered as to their nature by a comparison with modern forms. But fortunately some specimens have been found with impressions of the softer parts. We thus learn that they were furnished with a fin on each side of the body, that there were eight arms and two long tentacles, that the suckers were armed with horny hooks, and that

the mouth had mandibles. Doubtless they could dart through the water with great rapidity (Chapter X).

There were plenty of *Fishes* in the Jurassic sea. They belonged to the ganoid and placoid orders (Chapter V). Here sharks appear for the first time. A great many fossil teeth are found. Many of them had flat teeth for crushing shell-fish, on which they fed. A fish like the Port Jackson shark must have been very plentiful.

We must now pass on to consider the *Reptiles*, a class which flourished very vigorously during this and the succeeding Cretaceous period. The reader will remember that reptiles of the present day are divided into four orders, while the extinct forms are so numerous and varied that they can hardly be got into five separate orders. Of living orders turtles, snakes, lizards, and crocodiles are examples, while of extinct orders we have already said something about plesiosaurus, anomodonts and dinosaurs. To begin with the living orders, we find that three out of the four have left unmistakable evidence of their existence—namely lizards, turtles, and crocodiles. The fossil lizards are not numerous, but they show a much stronger likeness to modern forms than those somewhat doubtful lizards of the Trias (Chapter XI). The *turtles*,[1] whose existence during Triassic times was doubtful—as we have only foot-prints to go by—here put in a genuine appearance.

[1] A fossil turtle has been found in the Trias of Germany. A German writer states that serpents have been traced back to the Cretaceous of France.

Some five specimens of true marine turtles have been found in the Portland Oolites. No remains of *serpents* have been detected in Jurassic rocks. With regard to the *crocodiles*, the highest living order of reptiles, the reader will remember meeting with them in the Triassic rocks. But they flourished quite as vigorously during Jurassic times. *Teleosaurus* was a Jurassic crocodile over 30 feet long, somewhat like the gavials of India. The extinct reptiles, of which we will now speak, have been divided by palæontologists into nine orders, as follows :—

Order 5.	Ichthyopterygia	Ex. Ichthyosaurus.
„ 6.	Sauropterygia	Plesiosaurus.
„ 7.	Pterosauria	Pterodactylus.
„ 8.	Anomodontia	Dicynodon.
„ 9.	Dinosauria	Iguanodon.

The first four are the living orders already referred to. We will now take these in order.

Plesiosaurus occurs in the Trias, and was described in Chapter XI (see Fig. 12). This order was abundant in the period of the Lias, associated with *Ichthyosaurus*, of which we must now give a brief account (Fig. 14). It was a huge and powerful reptile, of fish-like form (hence its name, which means fish-lizard), from 20 to 40 feet long, provided with four limbs in the form of paddles, each composed of a number of little bones, which doubtless were used much in the same manner as the whale uses his "flippers." One specimen has been found which shows an exact impression of the skin of the hinder paddle. This is

the only indication we have of the nature of the creature's skin ; but in the absence of scales, or bony plates, we may conclude that it was smooth, or wrinkled. The flexible limbs tell their story. They imply that the creature was a powerful swimmer, haunting the sea—for its remains are only found in true marine deposits. The long tail (which probably had an expansion of the skin at the end in the shape of a paddle such as a whale has) confirms this idea. Thus the tail and paddles together would constitute a powerful swimming apparatus. The vertebræ (cup-bones, collectors call them) are biconcave, like those of a fish, thus rendering the spinal-column very flexible. It is, however, probable that at times the ichthyosaurus came to the shore ; for a strong bony arch is seen supporting the fore-paddle, which, it is thought, would render locomotion of some sort possible. The head is very large and long, the powerful jaws being well provided with conical teeth, suggesting decidedly carnivorous habits. And this

Fig. 14. The Fish-lizard (*Ichthyosaurus*).

conclusion is borne out by an examination of the "coprolites," or petrified droppings (Fig. 14), which show numerous fragments of unfortunate ganoid fishes devoured by this voracious creature. The eyes were very remarkable, being large and protected outside by a curious ring of bony plates, the use of which is rather a matter of speculation. A great many specimens of ichthyosaurus have been found, and a good many species distinguished.

The next group, or order, we have to consider is the very extraordinary race of flying reptiles, the *Pterosauria* (or winged-lizards), better known as pterodactyls (wing-fingered), because they had a very elongated little finger to which was attached a large and thin membrane, which when spread out acted like the so-called wing of a bat, and thus they may be said to have had wings on their fingers. In this way they were endowed with considerable powers of flight. They were not bats, for bats are mammals, while these creatures were, on the whole, reptiles. Also the bat has *all* its fingers elongated to support the flying membrane. In some cases the membrane was attached to the hind-limb as well as to the fore-limb. The first specimens of these wonderful creatures ever found were thought to be bats, and even good anatomists have mistaken their bones for those of birds. We must be careful not to speak of the membrane as a wing. It was very different from the wing of a bird and had no feathers on it. We must call it the "volant membrane." One very beautiful specimen from the Solenhofen stone shows an exact impression of the volant membrane, and

gives no sign of feathers, or of anything but a smooth, possibly downy surface. But even if the fore-limbs of pterodactyls had not been preserved, we should still have reason for thinking, they could fly on the strong keel-bone to which powerful muscles were attached for the rapid movement of the fore-limbs, and in the perforated bones, giving lightness and supplying air for the vigorous oxidation of the blood, as in birds.

A large number of the bones of these creatures, and a considerable series of complete skeletons, have been found in the Jurassic and Cretaceous rocks of America. Yale College, U.S., has 600 specimens from the Cretaceous rocks! The majority of them were small, but some of the American Cretaceous forms indicate an expanse of more than 20 feet from tip to tip of the wings (Chapter XIV). A bat walks on all fours with the membranes folded up, and probably pterodactyls could do the same. There is also reason to think that they could stand erect like birds, from which position they could the more easily expand their wings for flight. They lived over land and water, and perhaps could row themselves over the surface of a lake; many of them had teeth, so they must have pursued something more substantial than dragon-flies—probably fish and small mammals. As lords of the cliff they would get whatever could be conquered by tooth and nail. We even know the structure of their brains, for in the Cambridge Greensand (of Cretaceous age) have been found casts of the interior of the skull in phosphate of lime. From this evidence Professor

Seeley, from whose book on Pterodactyls some of the above remarks are taken, concludes that the pterodactyl was an intelligent creature, with a near relationship to birds. They are, however, on the whole more reptilian than avian. The presence of teeth implanted in separate sockets is a reptilian character, and their tails were composed of separate vertebræ. One very beautiful and slender genus was *Rhamphorhyncus phyllurus* from the Solenhofen stone, showing a long and narrow volant membrane and a long tail, the end of which was expanded into a kind of paddle-shaped membrane, doubtless used as a rudder to guide the creature's flight, and perhaps serving, like the tail of a kite, as a kind of balance. We shall meet with more of these weird creatures in the rocks of the Cretaceous period (Chapter XIV).

The *Dinosaurs* are the last and highest order of extinct reptiles. The name implies "terrible lizards," and they are rightly named, for some of them, especially those that were of carnivorous habits, must have been very terrible. However, if we take mere size, the herbivorous families were the most imposing, and attained to dimensions that seem hardly credible. As far as we know they began their existence in the period of the New Red Sandstone and continued all through the Mesozoic era. Of Triassic dinosaurs we have already spoken. Professor Marsh, to whose investigations of American dinosaurs all geologists are greatly indebted, divides the Jurassic forms into five orders, which we will now enumerate, giving the English of the Latin names which he has chosen.

I. The *lizard-footed.* Vegetable feeders of very

great size, with fore- and hind-limbs of nearly equal length, walking on all fours and with the limb-bones solid. In this group occur such forms as *Atlantosaurus*, nearly 100 feet long. *Brontosaurus* was 50 feet long and calculated to have weighed 20 tons. *Cetiosaurus* is another monster of this group, described by Professor Phillips (p. 212).

II. The *plated lizards.* So named because the skin was provided with an armour of bony plates. Some were of gigantic frame. The front limbs were small, but the hind-limbs large. Probably they walked on all fours. The bones were solid. *Scelidosaurus* from the Lias is an example.

III. The *bird-footed.* These also were herbivorous, with hind-limbs so much larger than the fore-limbs that they show an approach to the type of birds. It is almost certain that they habitually sat in an erect position. The limb-bones were hollow, another bird-like character. Some were of great size—like the *Iguanodon* of the Cretaceous period, which has left some gigantic and three-toed footprints, as well as bones, in the Wealden strata. It was about 30 feet long (see Fig. 13).

IV. The *beast-footed.* These were formidable carnivorous creatures, which generally walked erect, their progression being, in many cases, assisted by a very powerful tail, which they may have used in leaping, as kangaroos do. The fore-limbs were very small (as in kangaroos), and had prehensile claws. Their limb-bones were hollow. *Megalosaurus* and *Ceratosaurus* are examples.

V The *leaping-footed.* These curious creatures

—which are only doubtfully referred to the dinosaurs by Professor Marsh—had very curious hind-feet, specially adapted for leaping, and they probably had very considerable powers in this direction.

There is one form of dinosaur which presents more bird-like affinities than any other, viz. the little *Compsognathus longipes* from the Solenhofen stone. It is so peculiar that Professor Marsh places it in a group by itself. It had toothed jaws and the head was supported on a long and slender neck. Professor Huxley concludes that "it is impossible to look at the conformation of this strange reptile and to doubt that it hopped or walked in an erect or semi-erect position, after the manner of a bird, to which its long neck, slight head, and anterior limbs must have given it an extraordinary resemblance."

As we remarked in Chapter XI, p. 174, the evolutionist believes that birds and reptiles were developed from some common form. Is it possible that Compsognathus represents the stage at which the bird-type was very nearly reached? Who shall say? Besides these five or six groups there are some curious slender little creatures whose relationships are hardly yet known, called the *Cœluria* (or hollow-tailed). Their bones show great lightness; for instance the cavities of the vertebræ are (proportionally) even larger than in pterodactyls. Even the ribs were hollow. They had a long curved neck and a long weak tail. They show a suggestive likeness to birds and pterodactyls. But Professor Marsh thinks that probably they were little dinosaurs which haunted the trees. This would explain their lightness and small size.

We must now conclude our brief account of Jurassic reptiles with one or two descriptions of particular dinosaurs. First we will take *Cetiosaurus*—one of the first group, the lizard-footed. The following extracts are from Professor Phillip's account of this gigantic creature: "Probably when 'standing at ease,' not less than 10 feet in height, and of bulk in proportion, this creature was unmatched in magnitude and physical strength by any of the largest inhabitants of the Mesozoic land or sea. [This was written before some larger American forms were discovered.] Did it live in the sea, in fresh water, or on land? This question cannot be answered, as in the case of Ichthyosaurus, by an appeal to the accompanying organic remains, for some of the bones lie in marine deposits, others in situations marked by estuarine conditions, and out of the Oxfordshire district, in Sussex, in fluviatile accumulations. Was it fitted to live exclusively in water? Such an idea was at one time entertained in consequence of the bi-concave character of the caudal vertebræ, and, it is often suggested, by the mere magnitude of the creature, which would seem to have an easier life floating in water than when lifting its huge bulk and moving with slow steps along the ground. But neither of these arguments is valid. The ancient earth was trodden by larger quadrupeds than our elephant." He then points out that the articulation of the bones points to walking on land; but he thinks it may have been amphibious, and concludes: "We have therefore a marsh-loving or river-side animal, dwelling amidst filicine, cycadaceous, and coniferous

shrubs, and trees full of insects and small mammalia. What was its usual diet? If *ex ungue leonem*, surely *ex dente cibum.* We have indeed but one tooth, and that small and incomplete. It resembles more the tooth of iguanodon than that of any other reptile; for this reason it seems probable that the animal was nourished by similar vegetable food which abounded in the vicinity and was not obliged to contend with Megalosaurus for a scanty supply of more stimulating diet."

Brontosaurus. One of the American Jurassic dinosaurs, of the lizard-footed group, was nearly 50 feet long, and is estimated to have had a live-weight of 20 tons. It had a small head, large tail, and solid bones. The small head and brain indicate a stupid, slow-moving reptile. It was entirely without offensive or defensive weapons, or bony plates on the skin, as some had. It was more or less amphibious, and probably fed on aquatic plants and other succulent vegetation. Perhaps the specimens which have been found became mired, and so died in the mud.

Stegosaurus. One of the plated lizards, was the strangest of all the dinosaurs. It would seem to have been well equipped with armour, for it had bony plates on its skin, and its back was armed with spines. It was about 30 feet long, and had very large hind-limbs, with smaller fore-limbs. Probably it could walk on its hind legs; and it had a big tail (Marsh, *American Journal of Science.*)

One of the dinosaurs had a horn, and so has been named *Ceratosaurus* (horn-saurian). This

is a new feature. The horn must have been a powerful weapon, if we may judge from the rhinoceros. It belongs to the "beast-footed" group and was a ferocious flesh-eating dinosaur. In concluding our account of dinosaurs we may mention that the largest of all, *Atlantosaurus*, far excelled the Cetiosaurus in size, its length being not far off 100 feet.

Perhaps the most anomalous of all the creatures of this period was the *Archæopteryx* (or ancient winged creature, see Fig. 15). It is generally considered to have been a bird, and it certainly had feathers and claws like a bird. But what can one say to a bird with teeth in its jaws and with a long tail like that of a reptile, except for the feathers, fastened on to it in a very peculiar way? Its vertebræ were bi-concave, like those of some extinct saurians, and its wings had claws sticking out. If it were not for the feathers perhaps no one would call it a bird. It unites characters of birds and reptiles in a most remarkable way. In size it was about as large as a rook. Are we to call it a pterodactyl with feathers? That would be to dub it a reptile, and since the leading authorities have called it a bird, we must abide by their decision. Names, however, are not very important; the main fact we have to remember is that in former ages some classes of animals which now are sharply marked off from each other were by no means so separated. There is one specimen of Archæopteryx in London with the head missing, but otherwise very perfect, the impressions of the feathers being easily recognised. The other, which

has a head, was discovered more recently and is now in Berlin. They are of priceless value.

Finally, we cannot conclude our survey of the life

Fig. 15.

Remains of Archæopteryx from the Solenhofen Slate.

of this period without referring to certain interesting remains of a still higher class, namely, Mammals, which have been found in the Stonesfield Slate and in the Purbeck strata. These remains consist chiefly

of jaw-bones. They have been carefully compared with the jaw-bones of animals now living, and there can be little doubt that they belonged to marsupials or "pouched animals," such as we find in Australia at the present day. Some of them were certainly insectivorous. One resembled the banded ant-eater (Myrmecobius) of Australia. They were of small size. Another (Plagiaulax) is considered by some to have resembled the kangaroo-rats of Australia. Others are thought to resemble the American opossums.

It is a very striking fact that the flora and fauna of the Jurassic period show a decided likeness to the present flora and fauna of Australia. This is seen in the cycads, tree-ferns, araucarian pines; in the molluscs, such as Trigonia; in the fishes, in the Port Jackson sharks, and in the mud-fish (Ceratodus). It is true that there are no dinosaurs in Australia. But dinosaurs have had their day. There are, however, plenty of marsupials in that country, and some resemble Jurassic forms. It would seem, then, that no region of the globe has been so slightly affected by the changes in plants and animals since the Jurassic period as Australia. Doubtless it was isolated from other parts of the world at an early date, and so the higher forms of mammals could never get there.

CHAPTER XIV

THE CHALK DOWNS

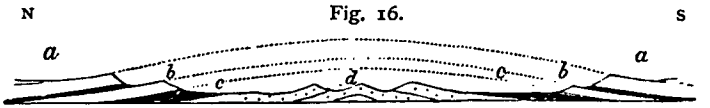
"The distribution of land and sea in particular regions does not endure throughout all time, but it becomes sea in those parts where it was land, and again it becomes land where it was sea."—ARISTOTLE in his *Meteorics*.

To find the records of the period of the earth's history now about to be considered, we must go to the Chalk Downs of Surrey or Sussex. From these hills may be seen nearly all the different groups of rocks to which the name *Cretaceous* has been given by geologists, the Chalk formation being the most conspicuous among them. Hence the title of the present chapter. The whole district between the North and South Downs, known as the *Weald* (wold or wood), is entirely overlaid by Cretaceous rocks (see Fig. 16). The chalk, with other Cretaceous rocks, will also be found in East Anglia, on Salisbury Plain, and in Dorsetshire, also in the Isle of Wight. In accordance with the plan of other chapters, we will first see what the *Cretaceous*[1] rocks are; secondly,

[1] The word Cretaceous is derived from the Latin *creta*, meaning chalk.

consider how they were formed, touching on the climate and geography; and thirdly, briefly survey the plant and animal life of the period. The first thing to remark about the Cretaceous rocks is their very varied character (more so than the Jurassic),

Fig. 16.



Section across the Weald.

a, *a*, Upper Cretaceous strata, chiefly chalk, forming the North and South Downs. *b*, *b*, Escarpment of Lower Greensand with a valley between it and the Chalk. *c*, *c*, Weald Clay, forming plains. *d*, Hills formed of Hastings Sand and Clay. The Chalk, etc., once spread across the country, as shown in the dotted lines.

sands, sandstones, clays, phosphatic deposits, fresh-water limestones, chloritic sands, chalk marl, white chalk, and bands of flint all occurring somewhere in the series. These facts alone testify to very varied physical conditions. The whole series of strata is not much less than 7000 feet in thickness.

Taking the different divisions in ascending order we have first the *Wealden strata*, mostly found in the Wealden district and about 1500 feet in thickness. They contain clays, loose sands, sandstones, and shelly limestones; and the fossils they contain tell us that they were formed in fresh water. These pass insensibly into the *Lower Greensand*, which is 850 feet thick, and shows alternations of sand, sandstones, clays, and occasional limestones with marine fossils, indicating that they were formed in the sea. The name greensand, however, is unfortunate, as it is only occasionally that some of the

sands are green from the presence of silicate of iron. In its place the name Neocomian is often used, and the Wealden beds called Lower Neocomian. The Neocomian group constitutes the lower division of the Cretaceous rocks. In the upper division we have first the Gault, a stiff, dark-coloured clay. It is seldom more than 100 feet thick, often much less, and has a beautifully preserved series of fossils. The Upper Greensand (or Chloritic series of Lyell) consists of sand and sandstone, etc. It is, however, not always green. But when the sand is green it is due to little grains of a green mineral called glauconite. Under the microscope many of these little green grains turn out to be casts of foraminifera. It is found in the Weald, in the Isle of Wight, and in Dorset and Wiltshire. But it dies out to the north-east. At Cambridge there is a remarkable stratum below the Chalk Marl, and resting on an eroded surface of Gault, which contains a band of so-called coprolites. These have been the subject of much consideration on the part of geologists. Many of them are nodules of phosphate of lime, and a considerable number have been shown to be phosphatised sponges. They probably were formed by segregation out of mud saturated with phosphate of lime.

Many interesting and valuable fossils have been found in this seam, which resembles the Greensand, namely, bones of reptiles, such as pterodactyls, ichthyosaurs, plesiosaurs, dinosaurs, and turtles, many fish remains, numerous shells of mollusca, small crabs, echinoderms, corals, etc. Many of

the fossils have been washed out from the Gault below, and so become part of a stratum to which they do not belong—petrified anachronisms, like Roman mosaics let in to the floor of an old English mansion. On this interesting stratum lies the Chalk Marl, of which the coprolite bed, where it occurs, is really the base.

The Chalk Marl is a muddy limestone at the base of the Chalk formation. To this succeed the Lower Chalk (without flints) and the Upper Chalk (with flints). The total thickness of the Chalk varies in different parts of the country, but it averages from 600 to 800 feet. In the Isle of Wight it is over 1000 feet. The Chalk covers a geographical area ranging from the north of Ireland to the Crimea, and from the south of Sweden to the south of Bordeaux—which proves that the Chalk sea was by no means small. Most people are familiar with the appearance of Chalk. It is a soft, white, fine-grained limestone, and is composed almost entirely of carbonate of lime. It is remarkably free from sand or pebbles, and signs of stratification are not easily perceived, except in the Upper Chalk, where the bands of flint evidently follow lines of stratification. Many interesting and beautiful fossils are found in Chalk—from humble little foraminifera (of which it is chiefly composed) to the bones of gigantic reptiles haunting the land and the sea of the Cretaceous period.

Such is a brief statement of the rocks of which we must endeavour to interpret the story. Going back for a moment to Jurassic times, it is clear that in the Purbeck beds we have evidence of the com-

mencement of those fluviatile and estuarine conditions under which the Wealden strata were deposited. That the Wealden rocks were formed by some great river seems to admit of little doubt, though some consider them to have been formed in a large fresh-water lagoon. They are succeeded by marine strata. The evidence for their fresh-water origin is quite clear. Thus we find fresh-water mussels (unio) and immense numbers of the little fresh-water crustaceans known as cypris or the "water-flea," also river shells such as cyrena, bones of terrestrial reptiles, foot-prints of the great iguanodon, and stems and leaves of land-plants. Also the absence of ammonites, belemnites, corals, etc. (found in the beds above), tells in the same direction. There are, however, a few marine types at certain levels, such as oysters and other marine shells. Such facts tell us that at times the sea encroached somewhat farther into the estuary of the Wealden river. This might easily be caused by a slight subsidence of the delta, or by a decrease of the power of the river itself—for river and sea would be continually struggling together for the mastery, and an estuary is a kind of debatable ground where the two meet. We can form some idea of the size of the delta; for Wealden strata are found also in Dorset, in France, and in North Germany. Taking these as limits, we require a delta as large as that of the Ganges at the present time. Also there is some reason to think that it flowed from west to east like the Thames. Probably there was a continent occupying what is now the Atlantic Ocean, or rather a part of it. It must be

remembered that the Wealden strata represent only a local phase of the geography of the period; and while they were being formed marine conditions prevailed elsewhere. After a time the great delta sank and the sea came over those parts, and in that sea the Lower Greensand or Upper Neocomian rocks were formed. But in some parts of Britain no rocks were forming then, and there was dry land. Evidently there was some denudation taking place before the time of the Upper Cretacebus rocks, for the Gault was formed in deeper water. The subsidence continued till the end of the Cretaceous period, reaching its maximum at the time of the White Chalk. This is clearly proved by the nature of the strata, as well as by the fossils they contain. To state the evidence fully would take more space than can be spared, but the reader will now have a general idea of its character. Above the Gault lies the Upper Greensand or Chloritic Sand. Speaking of the latter, Sir Charles Lyell says: "The Chloritic Sand is regarded by many geologists as a littoral (shore) deposit of the Chalk ocean, and therefore contemporaneous with part of the Chalk Marl, and even perhaps with some part of the White Chalk. For as the land went on sinking and the Cretaceous sea widened its area, white mud and Chloritic Sand were always forming somewhere, but the line of the seashore was perpetually shifting its position. Hence, though both sand and mud originated simultaneously, the one near the land, the other far from it, the sands in every locality where shore became submerged might constitute the underlying deposit."

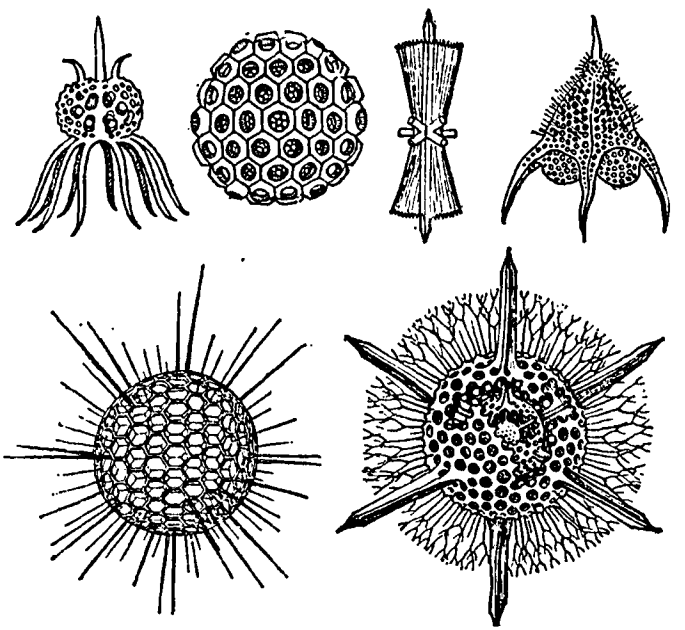
We have now to consider how the Chalk was formed—a question on which much might be said. We will endeavour to deal with it briefly. It will be remembered that in Chapter VII, on the Mountain Limestone, this subject was introduced, and it was pointed out that the grey mud brought up from the bed of the Atlantic was largely made up of microscopic shells called foraminifera. Now there is no doubt that foraminifera, and especially the genus globigerina, make up a very large percentage of the "globigerina ooze," but not so much as 85 per cent, as Huxley estimated. Later researches show that 60 per cent would represent the calcareous matter, and 20 to 30 per cent the silica, the rest being magnesia and iron, etc. That this ooze and the Chalk are closely related admits of no doubt, but it is not yet proved that they are identical. When we come to examine chalk under the microscope we find that much of it shows no trace of organic structure; and the question naturally arises, how much is due to foraminifera and other organisms? and whether or not some portion of it may have had a purely chemical origin, and been precipitated from solution. Professor Sorby, who has carefully studied the question of the origin of limestones, says that foraminifera would not make up half the bulk of the Chalk. He considers that a large portion is due to the breaking up of shells (especially one called inoceramus), echinoderms, and other calcareous bodies. His conclusions are the result of thorough microscopic examination, and carry much weight. It is quite possible that some small portion may be

due to precipitation of lime—a process which we have seen possibly contributed to the formation of Oolitic limestones.

We have consulted the microscopists on this question. Let us now consult the chemists. They will tell us that chalk has not the same chemical composition as the globigerina ooze, though of course it shows some similarity. It is deficient in silica. Now if the chalk and the ooze were both formed in the same way we might expect an agreement in their chemical constitution, especially as chalk shows a very uniform composition. The want of agreement, however, must not be pressed too far; for it can be partly explained by supposing that changes took place in the Chalk during the lapse of subsequent ages. This is very probable, and it seems pretty clear that *one* kind of change has taken place, namely a separation of the silica from the lime. The Upper Chalk shows bands of flints in regular layers. How have these been formed? To answer this question we must take evidence from the globigerina ooze and from the flints themselves. The samples of ooze which have been brought up always show under the microscope a certain proportion of little siliceous organisms of very great beauty, known as polycistinæ (see Fig. 17), also spicules of sponges (composed of flint), and frequently, little siliceous structures of great delicacy, known to belong to minute plants called diatoms. And so these constitute three sources of silica or flint. It is believed that the silica thus provided, having slowly separated from the mass of the Chalk by a process of segrega-

tion, has helped to form the flint nodules. And on turning to the nodules themselves we find their testimony in favour of the idea. Their very shape, so irregular and lumpy, suggests some such action as we know to have formed "concretions" in other rocks.

Fig. 17.

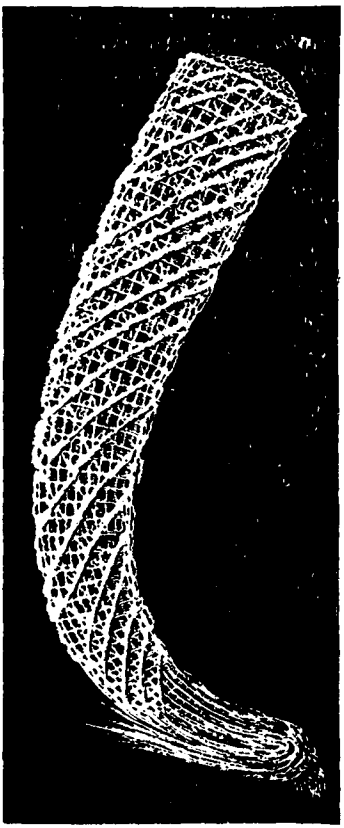


Microscopic Flint Shells (Polycistinæ).

But, more than this, they are shown to be intimately connected with siliceous sponges. Many of them on being broken open are found to contain sponges more or less perfectly preserved in their interior; but frequently only a cast of a sponge is seen.

Siliceous sponges often have a beautiful framework of silica, looking like glass spun out into very fine threads and woven into fantastic forms. This framework supports the flesh of the sponge, which is in reality a colony of creatures all living together, like the polypes of compound corals. It seems then that such sponges lived and died on the bed of the Chalk sea, and that as the fleshy matter decayed silica collected round them, and probably grew round them, long after they had been buried in calcareous ooze. Silica is found to be present in sea-water, and this must be the source whence sponges, polycistinæ, and diatoms get their silica. The "euplectella" is a very beautiful siliceous sponge frequently dredged up from the depths of the sea, and commonly called "Venus's flower-basket" (see Fig. 18). We may therefore conclude that the bands of flint nodules mark the

Fig. 18.



Venus's Flower-basket—a Siliceous Sponge.

site of old sponge beds. Should it be suggested that the Chalk might be partly formed of corals and coral débris, we must reply that the evidence of the Chalk itself is quite against the notion. No signs of coral-reefs are found there; and what corals are found are not reef-builders, and far from plentiful. Moreover, the Chalk sea was too deep for coral-reefs. It will be instructive if we now ask the reader to consider the question of the depth of the old Chalk sea. We have just stated that it was not shallow. Was it very deep, or only of moderate depth?

Let us take evidence on this point; for if we can arrive at any satisfactory conclusion, it may help us in forming conclusions with regard to the geographical and other conditions of the period. *In the first place*, the very fact that the chalk is an organically formed deposit, implies that it originated in regions of the sea removed from those supplies of sand and mud which cause the growth of strata near the shores of continents, that is, in comparatively shallow water. The Chalk is practically free from land-derived detritus, though Professor Sorby has detected grains of quartz. *Secondly*, the absence of coral-reefs, which can only be formed in shallow water. *Thirdly*, we have evidence from the forms of life preserved in the Chalk. Taking a general view of the Chalk fauna, naturalists find that it is distinctly related to that of the globigerina ooze of the Atlantic. A good deal of dredging has now been done in the deeper parts of the ocean, and this line of research has opened up new fields to the naturalist, and at the same time afforded most valuable in-

formation to the geologist, in fact the kind of information that is at the present time sorely needed. Before this line of inquiry was originated naturalists were not aware that there was any deep-sea fauna at all. The depths of the ocean were looked upon as barren wastes, as lifeless as they are dark, save for gleams of phosphorescent light shed by many of the creatures inhabiting "the depths of the sea." Clarence in his dream saw—

> "A thousand fearful wrecks,
> A thousand men that fishes gnawed upon;
> Wedges of gold, great anchors, heaps of pearl."

But now the state of matters in these inaccessible regions is not left entirely to the imagination, and the scientist can form some kind of picture of the processes there going on, and even of the kinds of creatures haunting its deep recesses. It has now been proved that even the deepest recesses of the ocean, where the depth is more than 4000 fathoms, are peopled with creatures adapted to such conditions. Now on applying the knowledge thus gained we find a distinct relationship, as already stated, between the fauna of the Chalk and that of those moderately deep parts of the Atlantic Ocean where the ooze was found.

This relationship shows itself in the Foraminifera, nineteen species of which are identical; in the sponges, which are related to the "ventriculites" found in the Chalk, and also in the echinoderms or sea-urchins. It will not be necessary to go farther into detail on this interesting question. The sum and substance of the evidence is that the Chalk was formed in an open

warm sea of moderate depth, and a good deal deeper than that of the Jurassic period.

The exploration of ocean-beds has brought to light another very singular deposit now forming both in the Atlantic and Pacific Oceans, and called the "Red Clay." It was found that beyond depths of 2500 to 3000 fathoms the ooze came to an end and its place was taken by a red clay. In the very deepest soundings it was brought up. How was it to be explained? It could not be sediment derived from land. Mr. Murray, who studied these matters during the famous and fruitful voyage of H.M.S. *Challenger*, came to the conclusion that volcanic dust was the source whence the Red Clay came. He showed that, contrary to general belief, volcanic dust is universally present on the surface of the ocean; and it is believed that no small amount is supplied by volcanic submarine action. The marine denudation of volcanic islands also supplies a fair share of this material. The red colour was explained as due to the oxidation of iron. The fact that the globigerina ooze contains a little clay and occasional fragments of pumice confirms the above explanation. This was a great discovery; for it revealed to us what is taking place in the very abyss of the ocean, and it told of a new and quite unsuspected method of rock-formation.

We have introduced this question of the Red Clay because it bears indirectly upon that which we have just been considering — the depth of the Chalk sea. It tells us plainly that the Chalk could not have been formed in the very

deepest parts of the sea, and so confirms the conclusion already stated, that the Chalk sea was only moderately deep. It should also be added that the Chalk fauna does not show any *marked* relationship to that of the abysmal regions where the Red Clay is found. But this discovery opens out further considerations, for the question at once arises, "Is there any sign of a Red Clay formation in any of the stratified rocks?" The answer seems to be "No." And if not, we must conclude that the deepest recesses of the ocean have never been upheaved to form dry land and to build up continents, and so it may with good reason be concluded that the recesses of the Atlantic and Pacific Oceans have remained undisturbed through all those long geological periods with which the geologist is concerned. On these and other grounds many geologists believe in the doctrine of the permanence of ocean-basins. If this doctrine be true, then all the known stratified rocks must be regarded as deposits formed in regions somewhat near the shores of continents; and during the whole of this vast space of time one slow but continuous deposit of Red Clay must have been forming in the abysses of the Atlantic and Pacific Oceans!

Before passing on to the survey of the plants and animals of the Cretaceous period, let us endeavour to gain some idea of the geography of the time. The sea of the lower Cretaceous rocks (Neocomian) was shallow and not extensive in Britain. The Gault marks a great subsidence, the effect of which was an advance of the coast-line and an enlarging of

the sea as more land sank. In this way the Cretaceous sea spread westwards until it reached Devonshire and the borders of Wales. The Upper Greensand marks the shore-deposits of the Chalk sea. Subsidence continued, and the sea was deepest at the time the Upper Chalk was formed. Judging from the large area occupied even now by the Chalk, we conclude that at that time it must have extended eastwards from the Atlantic into Asia, occupying not only the Mediterranean, but the plains of France, Germany, Italy, Spain and Northern Africa. In a westerly direction we may trace it across the Atlantic into the southern parts of North America. Probably there was land between Norway and Greenland, and in this way the cold water of the Arctic seas was kept out, and the temperature of the Cretaceous sea was maintained by currents from the south. That it *was* a warm ocean cannot be doubted, seeing the kind of creatures that lived in it. Returning to the British area the question arises, How much of Great Britain and Ireland were under water (Ireland was not then separated)? Taking the time of greatest submergence, the opinion of many eminent geologists is that the British area was a kind of archipelago, in which the tops of the mountains of Wales, Ireland, and the Highlands of Scotland formed islands. But it must not be supposed that the same mountains which we see now were in existence then. Snowdon, as a mountain, had no existence; for it was covered up under hundreds of feet of rock, and the mountains of those times were very much higher than the present ones

in this part of the world. The absence of chalk over these regions, or of any sign thereof, makes this conclusion somewhat uncertain. If we knew how high the old mountains were, there would be much less difficulty in speculating on this subject.

It now only remains to take a brief survey of the plants and animals of the period. The flora shows a very distinct advance upon that of Jurassic times. In the Lower Cretaceous rocks occur ferns, cycads, conifers; but in the Upper Cretaceous rocks are found the remains of a flora which resembled the existing vegetation. This is the case both in Europe and America. In the latter country we meet for the first time with the remains of such modern plants as tulip-trees, oaks, beeches, willows, poplars, magnolias. Such plants as these are high up in the scale of plant life. In European Cretaceous rocks other modern forms have been found. It may be said that with the Upper Cretaceous period a new era of plant life began, and that the higher types now prevailing claim descent from that period of the earth's history.

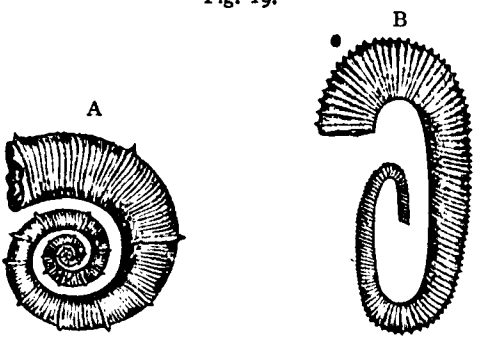
In the warm waters of the Cretaceous sea many forms of animal life flourished in great abundance.

Of foraminifera, corals, and sponges we have already spoken. Among the Mollusca we find cuttle-fishes (Cephalopoda) very abundant, as well as lower classes, such as the Brachiopoda and Gastropoda.

Ammonites and belemnites were in great profusion, but some curious new forms here present themselves, looking like ammonites unrolled—such

as scaphites and hamites (Fig 19). But we must pass to the vertebrate or back-boned animals. Fossil fishes are frequently met with in the Chalk, and here for the first time we meet with the "bony fishes" (Teleosteans), which have a completely developed

Fig. 19.



A. Crioceras. B. Hamites.

back-bone, and predominate in the seas and rivers of the present day. Among such have been recognised forms related to the salmon, herring, and perch.

The ganoid and placoid fishes were still fairly numerous. *Amphibians* were conspicuous by their absence; but *Reptiles* were still the predominating class. The orders represented by turtles, lizards, and crocodiles were fairly abundant, the latter haunting the rivers. The oldest known fossil serpent (Simoliophis) comes from the Cretaceous rocks. Turning to the extinct orders, we find that the pterodactyls, dinosaurs, and sea-lizards were still flourishing vigorously. But in American Cretaceous rocks there have been found one of the most extra-

ordinary reptiles yet brought to light, namely, the Elasmosaurus, with a long neck like that of a plesiosaur, and a long tail like that of an ichthyosaur. Its huge snake-like form had a length of 40 feet—a veritable "sea dragon." Speaking of this strange creature, Professor Cope says that it "probably often swam many feet below the surface, raising the head to the distant air for a breath, then withdrawing it and exploring the depths 40 feet below without altering the position of its body. It must have wandered far from the land; and that many kinds of fish formed its food is shown by the teeth and scales found in the position of its stomach."

Ichthyosaurs and *Plesiosaurs* still lived on. Our old friends the *Dinosaurs* were still flourishing. The fierce *Megalosaurus* and the herbivorous *Cetiosaurus* lived on from Jurassic times; but we meet with some new forms. Among such was the powerful *Iguanodon*, which, from a similarity in the teeth, takes its name from the little iguana now living in the tropical woods of America.

This ponderous dinosaur (iguanodon) was from 30 to 50 feet in length, and fed on the leaves of trees in the forests of the Wealden epoch. In these strata are found gigantic impressions or tracks, which it can hardly be doubted were made by this creature; but they show only three toes, and so have a strangely bird-like look. Iguanodon must have walked on its hind-legs. Later discoveries on the Continent have revealed every bone of this wonderful reptile (see Fig. 13). The fore-limbs were quite small.

The pterodactyls or wing-fingered race of reptiles

show some remarkable new forms, besides others like those of Jurassic times. These had pointed jaws entirely devoid of teeth, and have been found in great abundance in American Cretaceous rocks. Professor Marsh has given to this genus the name Pteranodon (winged-toothless). He states that more than six hundred individual skeletons of pterodactyls are now preserved in the Yale College Museum. Some were quite small, but others attained to a very great size, measuring about 25 feet from tip to tip of the wings. The long pointed jaws have a very bird-like appearance.

One more group of reptiles—perhaps the strangest of all—remains to be noticed. Of these only one species (*Mosasaurus*) has been found in the Chalk of Europe, but many others have been discovered in America. They must have been very serpent-like in appearance. Professor Cope calls them Pythonomorphs. They show points of resemblance both to serpents and lizards, and may well be called "sea-serpents." Some of them attained a length of 75 feet or more. They were very elongated in form, especially in the tail. Their heads were large, flat, and conical. For purposes of locomotion they were provided with two pairs of paddles, like the flippers of a whale. The tail would also be of service in acting as a propeller. On the roof of the mouth were four rows of powerful teeth; and it has been proved that, like snakes, they could swallow their prey entire. The skull of *Mosasaurus Camperi*, the only European species known, is 6 feet in length, and the teeth are truly enormous.

The reader will remember the strange bird-like and yet reptile-like archæopteryx described in the last chapter, and perhaps may still be hesitating whether to regard it as bird, or reptile with feathers. But we find that true birds lived in the Cretaceous period. Two species have been detected in the Cambridge Greensand. The Cretaceous strata of Kansas have yielded the entire remains of a considerable number of birds, which have been fully described by Professor Marsh. Some were like the wading birds of the present day. But two of them, *Hesperornis* and *Ichthyornis*, were very remarkable indeed. The former was a swimming and diving bird about 5 feet high, with small and rudimentary wings. It could not fly, but by means of its feet and a peculiar tail it could move rapidly through the water. Its long jaws were provided with teeth sunk in distinct sockets, thus reminding us of pterodactyls and the archæopteryx. In other ways also it showed a relationship to reptiles, and yet is undoubtedly a bird. It fed upon fishes. *Ichthyornis*, which was a much smaller bird, also had its jaws provided with teeth, but, having powerful wings, could fly. These strange birds, so unlike those of the present day, show to the anatomist signs of affinity with pterodactyls and dinosaurs. At present the ancestry of birds is unknown; but we should not be surprised if future discoveries prove them to be descended from dinosaurs.

CHAPTER XV

THE NEW ERA

"'So careful of the type?' but no
From scarped cliff and quarried stone
She cries, 'A thousand types are gone:
I care for nothing, all shall go.'"

TENNYSON—*In Memoriam.*

IT will be remembered that geological history is divided into four eras. So far we have traced the course of events through three of these eras, called respectively the Archæan, the Palæozoic, and the Mesozoic. These names remind us of that gradual approach towards living forms of life and wholesale extinction of old types which is one of the most striking facts brought to light by a study of the fossils contained in the series of stratified rocks. The present chapter will be devoted to the last era, the Cainozoic, distinguished from those preceding it by a very marked resemblance in its forms of life to those which we now find inhabiting our seas and continents. This resemblance becomes more and more marked as we follow the successive periods of the era, until in the latest deposits we find that the

forms of life were practically the same as those now living. As the Mesozoic era was marked by a great abundance and variety of reptiles, so the Cainozoic was distinguished by a wonderful development of a higher type of animals, namely, quadrupeds or mammals; some writers speak of it as the "Age of Mammals."

Each of the eras succeeding the Archæan was marked off from the preceding one by a long "break" or unrecorded interval. The nature of the evidence for such intervals was explained in Chapter IV. Now the interval between the Mesozoic era and the succeeding Cainozoic is marked, as the others are, by a "physical break"—that is, a want of continuity in the strata (see p. 44); and also by an "organic break"—that is, by a marked change in the fossils, showing that the "old order" had changed and new forms of life had appeared on the scene (see p. 48). We are now only speaking of the British area, but fortunately there are in other parts some record of this unknown portion of time. Thus in France there is the Pisolitic Limestone, and in Denmark the Faxoe Limestone, which deposits contain fossils showing them to be intermediate between the two eras; while in North America there is no want of continuity between the latest Cretaceous and the earliest Cainozoic strata, in fact it is somewhat difficult to draw the line between them. In England we always find the Cainozoic deposits resting in a greatly eroded surface of chalk, and thus learn that the close of the Cretaceous period was marked by an upheaval, so that

the Chalk strata became dry land, and consequently suffered largely from the erosive powers of "rain and rivers." How long this interval lasted we cannot tell. Probably it was not so enormously long as some authorities have maintained. This is the evidence for the "physical break" already alluded to. The "organic break" we will deal with presently.

The great task of classifying the Cainozoic rocks of Europe and determining their relative ages was accomplished by Sir Charles Lyell. They mostly lie in isolated patches and separate basins, wherein they were formed, and consequently the usual method —based upon superposition—fails. In the absence, therefore, of evidence showing one group overlying another, their relations had to be determined solely by a comparison of their fossils—a much less satisfactory method. For this purpose the Mollusca (shell-fish) were chosen as being most suitable. He determined the percentage of living species of Mollusca out of the whole number found in each separate group, and gave a name thereto which indicated the results obtained.

Thus the lowest group resting on chalk was found to contain only 3½ per cent of living species. This he named *Eocene*, or "dawn of the recent."

Another group found in France yielded 17 per cent. This was called *Miocene*, or "less recent."

The younger Cainozoic strata of Italy were found to contain from 36 to 95 per cent of living species, and were therefore called *Pliocene*, or "more recent."

And a still later group was found in which *all* the shells belonged to living species, and this was

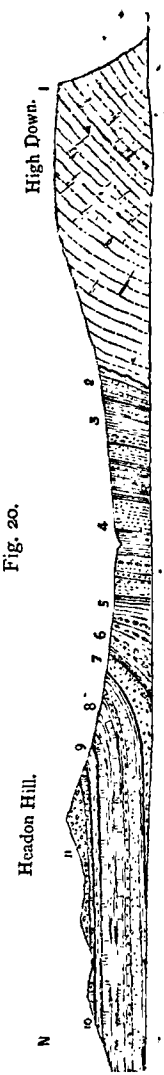


Fig. 20.

Section across the Isle of Wight from High Down to Headon Hill, showing the arrangement of the Chalk and Eocene Strata in Alum Bay. By H. W. Bristow, F.R.S.

1. Chalk. 2. Woolwich and Reading Beds. 3. London Clay. 4. Lower Bagshot Sand and Clay. 5. Bracklesham Beds, Barton Clay. 6. Upper Bagshot Sands. 7. Lower Headon Beds, Middle Headon Beds. 8. Upper Headon Beds. 9. Osborne beds. 10. Bembridge Limestone. 11. High level gravel (Post-pliocene).

called *Pleistocene*, or "most recent." It contained only a few remains of extinct mammals. This arrangement has, with a few changes, been universally adopted; though it still leaves much to be desired. Deposits in which the mammals as well as the Mollusca are of living species are called recent, and may be regarded as the closing sentences in the *Autobiography of the Earth*. We now proceed to a brief review of each of these four periods.

Eocene deposits are found in the London and Hampshire *basins*[1] (see Fig. 20), also in the Paris basin and in Belgium. In these regions they show numerous thin beds of clay, sand, and limestone, sometimes marine, sometimes of freshwater origin. They usually consist of loose and incoherent materials, de-

[1] A basin is a trough or syncline (Chapter IV).

posited for the most part in shallow water. Among Eocene rocks, the most widely distributed is the famous Nummulitic Limestone (not known in England). The sea in which this deposit was formed (mainly by foraminifera of the genus nummulites) stretched right across the Old World. We can trace it from the Pyrenees, through the Alps, Carpathians, Caucasus, Asia Minor, North Africa, Persia, Beloochistan, and the Suliman Mountains, and even farther east into China and Japan. This limestone is in some places several thousand feet thick, and forms a large part of the great mountain chains of the Old World.

Earth-movements on a grand scale must have taken place after this period, causing prodigious crumpling, folding, and crushing of enormous masses of strata. The great mountain ranges we have just mentioned were thus upheaved, and in course of time the agents of denudation slowly carved them out into their varied outlines of peaks, valleys, and precipices. In the London basin we have only Lower Eocene deposits. It is thought that they were deposited in a gulf or estuary, which opened out eastwards into a Belgian sea and narrowed westwards towards Wales, and into which a great river flowed from the west.

A number of shallow seas and lagoons were scattered about the north of France. Our English Eocenes are divided into local groups, which need not be here enumerated. Of these, the London Clay has yielded an interesting series of fossils indicating a warm climate, fruits of palms (Nipadites) being abundant. Passing on to the life of the period, we

find that the cycads, so abundant previously, have, almost disappeared, and the flora of Eocene times has a decidedly modern aspect. The lower forms of animal life flourished in great abundance, and we find in Eocene rocks fossil representatives of most of the invertebrate groups now existing. But whole families of Cretaceous forms have died out. Thus we no longer find the ammonites, belemnites, and hippurites, previously so abundant, while great orders of reptiles such as dinosaurs, pterodactyls, and pythonomorphs have vanished never to appear again. This striking absence of old forms of life, as well as the introduction of so many modern groups and species, constitute the evidence for the "organic break" between the Mesozoic and the Cainozoic strata. But all the modern orders of reptiles were living in Eocene times. Thus we find evidence of turtles, lizards, snakes, and crocodiles. Of these the *Palæophis typæus* (a fossil snake) of the Brackle-sham Beds is perhaps the most interesting. Its skeleton shows it to have been about twenty feet long, and like a boa-constrictor.

The remains of a large number of birds have been found in Eocene rocks. In fact nearly all the existing orders, such as swimmers, waders, runners, perchers, were flourishing vigorously at this time. But the London Clay has yielded the skull of a remarkable toothed bird, something like the Cretaceous Hesperornis and Ichthyornis, and named Odontopteryx. Professor Owen concluded that it had webbed feet and fed upon fishes. The teeth, however, are portions of the jaw itself,

and so resemble the teeth of a saw, which is peculiar.

The mammals, only feebly represented in the preceding era, now come forward as the "lords of creation." The rise and progress of this great and varied class, represented now by fourteen orders, throughout the Cainozoic era, and the introduction of more highly organised forms as time went on, is the most striking fact brought to light by the study of European and American Cainozoic deposits.

More than half the existing orders of mammals were flourishing in Eocene times; but some very strange forms are met with which do not fall in with any of the living groups. For these new orders have to be made, as in the case of many Mesozoic types of reptiles. Every year adds to our knowledge of the comparatively unknown groups, and already they serve to throw some light upon the possible origin and descent of forms with which we are familiar at the present day. In this line of research the evolutionist is presented with many interesting problems, some of which are on a fair way to being solved.

The mammals of this era are so numerous that it will be impossible to do more than single out some of the most important.[1]

Opossums and other marsupial-like animals abounded during Eocene times, some of which had

[1] The following are amongst living orders :—

Marsupials (kangaroos, opossums, etc.), *Edentates* (sloths, armadilloes, ant-eaters), *Cetacea* (whales, dolphins, etc.), *Ungulates*, or hoofed quadrupeds (horses, sheep, camels), *Proboscideans* (elephants), *Carnivora* (seals, bears, foxes), *Rodents* (hares and rabbits), *Cheiroptera* (bats), *Insectivora* (moles, hedgehogs), *Quadrumana* (monkeys, gorillas, etc.)

a liking for animal food, or, in other words, were carnivorous. Of *Edentates* no remains are known. The "Halitherium" or sea-cow was a sirenian, of which the dugong and the manatee are living examples. *Zeuglodon* was a whale, with remarkable teeth. The ungulates or hoofed quadrupeds were very numerous. Some of them evidently lived together in great herds, for many footprints of such are found in Eocene strata near Paris. Among those with an odd number of toes (one or three) was the Coryphodon, which resembled the tapirs of the present day, but was about the size of a rhinoceros. There were several tribes of tapir-like animals at this time. Of these the Palæotherium, first investigated by the illustrious Cuvier, is most familiar. He made a restoration of *Palæotherium magnum*, but recent discoveries have tended to modify his conception of it, and to show that it was "a slender, graceful, long-necked animal, more closely resembling in general figure a llama or certain of the antelopes" (Nicholson). It had a long flexible nose or proboscis for stripping off leaves, and it is believed that both the horse and rhinoceros are related to the palæotheres. Great herds of these creatures roamed over the fertile plains of France and the south of England during this period; for there was no "silver streak" separating the two countries then. In size they varied much, from that of a small pig to that of a horse. They have left copious footprints on the gypsum beds near Paris. These strata yielded a rich harvest of fossil remains to Cuvier, who astonished the scientific men of his day alike by his extraordinary

discoveries and his brilliant generalisations. The science of comparative anatomy may almost be said to have been founded by him.

The *Hyracotherium* (from American Eocene strata) was a small mammal no larger than a fox, resembling the peccary and the Syrian cony (Hyrax). By Professor Marsh it is called *Orohippus*, because it is believed that this is the primitive ancestor from which horses are descended. It had four toes, all with hoofs. The next stage in the evolution of the horse is represented by the *Anchitherium*, a creature with only three toes, with hoofs touching the ground. It occupies a place midway between the tapir-like palæotherium and the true horse. In size it resembled a small pony. Later on, in the Pliocene period, we find another stage, represented by the *Hipparion*, in which the third toe is very much bigger than the second and fourth (which did not touch the ground, for they were not wanted.) This animal was a kind of wild ass, and so was much more like a horse than anchitherium was. Later still, the second and fourth toes became mere "splint bones," one on each side of the big third toe, the result of disuse; for any organ or limb, if not used, will in time become "rudimentary," or even vanish altogether, as the legs of serpents have. In this way the last stage was accomplished, and Hipparion became a horse. The gap between the latter and Equus has now been filled up by the discovery of the Pliohippus in America, where also a complete series of those ancestral forms of the horse has been brought to light. In this way a chain of ancestors has been traced

connecting the little cony-like hyracotherium of the Eocene period with the noble horse of the present day —a result to which naturalists may well appeal as a powerful argument in favour of the theory of evolution. When the opponents of this once detested theory ask for "missing links," their objections may easily be silenced by an appeal to this wonderful series of ancestral horses. A still earlier type with the normal five toes, called *Eohippus*, or "horse of the dawn," has lately been discovered.

Among Eocene ungulates with an even number of toes were the *Anoplotherium* and the *Anthracotherium*—"generalised types" showing relationship with the hippopotamus, rhinoceros, pig, and horse. *Xiphodon* was probably the ancestor of the modern deer. Carnivorous quadrupeds flourished, some of which have left the marks of their teeth on the bones and skulls of palæotheres now lying in the gypsum beds near Paris.

Elephants (proboscideans) are not known to have existed at this time; but Professor Marsh has brought to light some huge American types intermediate between these and the ungulates. They had the size of elephants, but the habits of the rhinoceros. A pair of powerful tusks hung down from the upper jaw. On the head were three pairs of horns. The legs were thick and powerful, with five toes, like an elephant's; but they do not seem to have been provided with a trunk. In this strange group, which refuses to fit into our classifications of existing quadrupeds, the *Dinotherium*, *Tinoceras*, and *Unitatherium* are placed. Their brains were

remarkably small; but their great strength would probably compensate for any want of "artfulness." Lastly, we find in Eocene deposits representatives of even higher orders of mammals, such as bats (Cheiroptera), rodents, or gnawing mammals, Insectivora, and lemur-like apes (Quadrumana).

We now pass on to the Miocene period.[1] According to Lyell, Miocene deposits contain 17 per cent of living species of shells, that is, *more* than the 5 per cent of the Eocenes and *less* than the 36 per cent of the succeeding Pliocenes.

Records of this period are scarce in Britain. Such are met with in Devonshire at Bovey Tracey, in the Isle of Wight, and in Scotland in the Isle of Mull. In France and Switzerland and other countries the records are much more complete. At Ardtun in Mull the Duke of Argyll discovered a series of "leaf-beds" interstratified with sheets of basalt. They are followed by a succession of old lavas between 3000 and 4000 feet thick, also met with in Staffa and Skye. The lava is well seen at Fingal's Cave, where the hexagonal jointing, the result of cooling, is an interesting feature. Mull was then the site of a big volcano, long since denuded away. This volcanic series extends into the north of Ireland. The Giant's Causeway is an old basaltic lava of this period. All this district, now partly submerged, was then the scene of great volcanic outpourings. It extended up to the Faroe Isles and Iceland.

[1] The term Oligocene is now used for certain strata formerly classed as Upper Eocene and Lower Miocene, thus dividing the Cainizoic era into five periods.

Miocene deposits testify to an abundance of plant and animal life. The climate of North Europe and of the Arctic regions was very different from what it is now; for even in Spitzbergen Miocene deposits have yielded ninety-five species of plants such as now grow in England. The whole Miocene flora of Europe shows a resemblance to the present flora of North America in its warmer parts, and there is good reason to think that Europe and North America were connected by way of the Faroe Islands, Iceland, and Greenland. Most of Great Britain was then land.

Invertebrate forms of life are plentifully preserved in the Miocene rocks of different countries.

In Switzerland they have yielded a beautiful collection of fossil insects very like those of the present day, even butterflies being well preserved. The vertebrates are very numerous, especially the mammals. Among amphibians is a huge salamander, also from Switzerland, which was 5 feet long. Land-tortoises now put in an appearance. One remarkable tortoise (*Colossochelys atlas*) from India, exceeded any living tortoise in size; it measured about 20 feet from head to tail. The birds present no special features, but the mammals show some very remarkable forms. Among cetaceans the *Zeuglodon* of Eocene times was still living; but now the whalebone whales appear for the first time. Among the ungulates, or hoofed quadrupeds, we find a large number of forms, some quite new. Amongst those with an odd number of toes are members of the rhinoceros family, and tapirs such as *Lophiodon*.

Brontotherium was a remarkable American form resembling the tapirs in having a short proboscis, but differing from them in having a long tail and horns on the head. Some members of this family rivalled elephants in size. The hipparion (p. 245) was still living. Among even-toed ungulates we find a very large number of animals. Among such were the hippopotamus and the camel in India, pigs, musk-deer, stags, giraffes in India and Greece. Sheep and oxen are not known, but there were certain creatures intermediate between antelopes and goats.

The *Sivatherium*, from the Siwalik Hills of India, was a very remarkable horned creature of great size, showing relationship with antelopes. Three distinct types of proboscideans appear for the first time in Miocene deposits, namely *Dinotherium*, *Mastodon*, and the elephant (Elephas), but only the last has survived to the present day. *Dinotherium* was the least like an elephant; its lower jaw had two large tusks, bent downwards and backwards. *Mastodon* was decidedly elephantine, and had in some cases four tusks. The true elephants of this period come from India. It now only remains to add that the remaining orders of Carnivora, Rodents, Insectivora, and Quadrumana (monkeys, etc.) were all flourishing. The *Dryopithecus* was an "anthropoid ape" resembling the gibbon of the present day.

The next period is the *Pliocene*. As before stated, certain strata in Italy were found to contain 36 to 95 per cent of living shells, and were therefore called Pliocene. These deposits are found on

either side of the Apennines, in Sicily, and in other parts of the Mediterranean basin, where they attain a considerable thickness. In Britain we find but scanty records of this period. For the greater part of the time Britain was above water, and was subjected to a large amount of denudation. But eventually a gentle subsidence took place in the south-eastern counties, so that sand-banks and shelly deposits were laid down, just as they may now be forming in the North Sea. These deposits form what are now called "The Crags," a local term for certain shelly sands. Thus we have the White or Coralline Crag, the Upper or Red Crag, both in Suffolk, and the Norwich Crag. The Chillesford Beds, also of Suffolk, are now considered to be Pliocene. The Mollusca of the Coralline Crag indicate a temperate climate, while those of the Red Crag indicate colder conditions, and those of the Forest-Bed, a later deposit formed near the mouth of a river, show a still colder climate. Each contains a successively larger proportion of Northern or Arctic species. These facts tell us that a gradual refrigeration was taking place in our area during Pliocene times, a process which culminated in the Arctic climate of the succeeding Glacial period.

During this time the North Sea was a great plain over which herds of quadrupeds roamed into England; but this land was submerged by a downward movement which took place in Pliocene times, and the waters of the North Sea spread over the eastern part of England. This greatly altered the state of affairs, and cold water came down from the

Arctic Sea bringing with it Arctic species of shells. But the west side of Britain was warmed, as now, by the Gulf Stream. England and France were probably united; and it is likely that the waters on the eastern side spread through parts of France and so joined the Mediterranean waters. These two seas were probably kept apart by land to the north of Scotland.

With regard to the life of the period, the Mollusca afford valuable evidence of the change from the warm climate of the previous period to colder conditions. The other invertebrates are not of any special importance, and not very numerous. We therefore pass on to the *Mammals*. Nearly all the orders now known were flourishing; but we can only mention a few here. Among ungulates or hoofed quadrupeds were the *Tapir*, *Rhinoceros*, *Hipparion*, and the *Horse* (Equus), all belonging to the odd-toed division. In the larger group of even-toed ungulates were *Swine*, *Deer*, *Camels*, and the *Hippopotamus*. The latter is associated with remains of the elephant, mastodon, and rhinoceros. It is very probable that these formidable quadrupeds were protected against the severity of the climate by a coat of hair and fur. But if not, they may have migrated southwards for the winter. The *Dinotherium* of the previous period was apparently extinct. Among the Carnivora was a very formidable "sabre-toothed" tiger (*Machairodus cultrideus*), with enormous canine teeth shaped like curved daggers.

CHAPTER XVI

THE ICE-AGE AND ADVENT OF MAN

"Then the monster, then the Man;
Tattooed or woaded, winter-clad in skins,
Raw from the prime and crushing down his mate;
As yet we find in barbarous isles, and here
Among the lowest."

TENNYSON'S *Princess.*

IT is difficult to believe that the larger part of Great Britain was once buried up under a great series of glaciers united together to form one continuous ice-sheet, which buried mountains and lowlands, and that the climate of this country was such as we now find in Arctic regions. But this was undoubtedly the case, though it requires a considerable effort of imagination to picture "Merry England" with no bright green grass, no woods, no fertile valleys or pleasant streams, but simply one vast silent snow-field of dazzling brightness! Those, however, who have spent a winter in the Highlands of Scotland and seen the snows covering the Grampians, or traversed the glaciers and snow-fields of high Alps, have had, as it were, a glimpse of the "Great Ice Age" in

Britain, of which we will now endeavour to put before the reader a brief account, as far as this difficult and perplexing chapter in the Earth's autobiography has yet been interpreted by geologists.[1]

The evidences on which the above startling conclusion is based are so many and so convincing as to admit of no possible doubt whatever. But though the fact of the existence of a former period of intense cold in Northern Europe, Asia, and America is unmistakably recorded in a way that can be understood by the youngest beginner in geology, yet unfortunately the details and minor incidents of these times, now generally known as the Glacial period, are involved in a good deal of obscurity. As a rule the records of the oldest rocks, that is those which come lowest in the stratified series, having suffered from metamorphic changes, earth-movements, and other causes, are the most difficult to interpret. But here we find a curious exception to this general rule; for the glacial deposits or "drifts," as the scattered deposits of this period are called, though overlying all the other formations, and neither disturbed by subsequent earth-movements nor affected by subterranean heat and pressure, yet, with the exception of the crystalline schists underlying the Cambrian rocks, about which so many and various views have been held, present more difficulties than any other geological records. Perhaps glacial deposits may be compared to a book which has come to pieces, so that chapters and pages have got inextricably

[1] *Pleistocene* is the term frequently used by geologists to denote the deposits of this period.

mixed, and lie scattered over the floor. We may read a bit here and a bit there, but until put back in their original order, the separate pages and bundles of pages, however complete in themselves, are not of much use. So it is with the glacial drifts. They lie scattered over the face of the country, a portion here and a portion there, so that it seems hopeless to look for a continuous section in which the different members may be found lying over one another, thus revealing their order of succession. Nor is this the only difficulty, for, besides being patchy and fragmentary, they are by nature difficult to interpret. Clays, limestones, or beds of lava are geological documents much more easily interpreted than the stiff clays with angular fragments, or the irregular sands and gravels of which glacial drifts are composed. The reason for this lies in the fact that our knowledge of the origin and formation of other rocks is fuller and more complete. We can, as it were, watch them in process of making; but this is hardly the case with regard to such deposits as are found under glaciers, much less under a great continental ice-sheet. Glaciers are not, like rivers, transparent, so that we can see what is going on underneath, nor is it possible to make explorations beneath those parts which are actively engaged in manufacturing glacial débris. However, a vast number of explorers and geologists have recorded their observations, so that, especially of late years, much progress has been made. The literature of this subject is truly enormous, and will be found to contain a good deal of controversy and sometimes of

animated discussion. Ice and snow have, in this case, failed to bring about the cooling effects which they usually produce, and have sometimes been the subject of heated and even bitter controversies. But it is only by full and open discussion that the truth can ultimately be ascertained. Both in England and on the Continent the main question upon which geologists differ is, whether glacial deposits in the low districts have been formed mainly by an ice-sheet or by the action of icebergs and masses of floating ice in shallow water near coasts. But other questions, such as erosive power of ice and the motion of glaciers, have also been warmly debated. Into these controversies we cannot enter here, but will endeavour briefly to state the leading facts, and put before the reader such conclusions as at present they seem to warrant.

In order to understand the nature of the evidence upon which the existence of a former Arctic climate rests, it will be necessary to give a brief account of the effects wrought by ice at the present day, whether in the form of icebergs or glaciers; otherwise any description of glacial deposits will be useless. Unfortunately our knowledge of the behaviour and effects of continental ice-sheets, such as that which covers Greenland at the present day, is very limited. But even this hitherto unknown ground has been broken by Professor Nansen's brilliant journey, of which we heard so much last year. However, glaciers have been carefully studied both by geologists and others for some time; and we now possess a very fair knowledge of the effects

they produce. Icebergs and floating ice have also been studied, and it is chiefly in the light of the knowledge thus acquired that we must try to read the story of the glacial drifts. They will then become intelligible.

Let us take Switzerland, the best known land of glaciers, and see what is going on there at the present day. Having done this, we may go farther north in order to take a look at the icebergs and coast-ice of the Arctic regions. It will not be necessary to go into detail on this large subject, but only to point out briefly the more obvious and important geological effects of ice. We shall then return to our own country in a position to understand the numerous evidences for the Glacial period, and even to picture to some extent the appearance which it presented in those distant times, so near in a geological sense, and yet, if measured by years, so far away in the dim past. First, what is a glacier? Secondly, what does it do?

A glacier is a river of ice which slowly creeps down a mountain valley. It is continually being fed by snow falling in higher regions where the snow-fields are. When the snow falls it is loose and granular; but as fresh layers accumulate it becomes more compact. Now it is clear that these great layers of ice and snow will be impelled downward by the force of gravity, just as rain flows down from the mountains, only much more slowly. As it moves downward it becomes firmer, and gradually the separate granules are pressed together, and the air is squeezed out so that it becomes a compact blue mass

of crystalline ice. The downward motion is so slow that a glacier appears quite stationary, and it is only by putting in stakes and watching them change their positions that their movements can be observed. This requires a considerable amount of time. In all respects, except speed, glaciers flow like rivers. Like rivers they flow down valleys, and like rivers they transport a vast amount of material to lower levels. They also wear away and deepen the rocky valleys along which they flow. In summer, when the heat of the sun softens and partly melts the ice, they flow faster. Mr. J. D. Forbes found by careful measurement that the average daily rate of motion of the Mer de Glace of Chamouni in summer and autumn, was 20 to 27 inches in the centre, and 13 to 19½ near the side, where friction somewhat impedes its course. A glacier is traversed by fissures called crevasses. These are caused in the first instance by splits or cracks in the ice, such as are familiar to all skaters, and due to the same cause, namely bending. Ice, though a viscous body, that is behaving partly like a fluid, yet partly also resembles a solid; for it will not endure a sharp bend without snapping. Hence a glacier in descending down a valley frequently gets split. The cracks thus formed widen by degrees, until they expand into great chasms, which probably extend right down to the rocky floor beneath. Professor Tyndall and some other scientific men contend that glaciers behave like rigid bodies, and that their movements are accomplished by cracking and breaking up on bending round corners, and freezing up again when the broken portions are

pressed together. This curious phenomenon is explained on the well-known principle of regelation, and hence Tyndall's theory of the movement of glaciers is known as the "regelation theory." But many facts show that regelation alone will not account for the flow of glacier ice, which in many respects resembles that of a fluid substance falling slowly down the valley, as if it were pitch or melted sealing-wax; and the explanation put forward by Mr. Forbes may now be considered to be proved by the researches of that eminent man of science. Forbes maintained that ice in descending the valley behaved as a partly fluid substance, and his "viscous theory" contains a far more satisfactory explanation of the facts. It is granted that ice, when pressed beyond a certain point, does split and crack, but for all that it should not be regarded as a rigid body.

We have now to consider the second question and inquire into the geological effects of a glacier. These may be summed up in two words, namely *transportation* and *erosion*; for in the first place a glacier transports all the rocky debris falling on to its surface from the peaks, precipices, and mountain-sides along which it flows. The action of intense cold by night and considerable heat by day in the full glare of the sun, and also the corroding influence of the atmosphere and freezing of water in joints and cracks of the rocks, cause numerous fragments to be detached and fall on to the glacier below. In our own country every mountain-side and precipice shows numerous loose fragments lying below, all of which have been detached by atmospheric influences; but

when such fragments fall on to a glacier they are carried along on its surface (see Fig. 21). Some, however, fall down crevasses, and so reach the bottom, where they become cemented in the ice. In this way they are slowly carried down over the rocky floor of the valley, until at last they reach the end of the glacier, where in the warmer air the ice melts just as fast as it creeps down, and there they will be left to form a heap of stones, sand, and mud. Large blocks of stone quite different from the rocks on which they lie, and evidently brought from a distance, are called *erratics*. Sometimes they can be proved to have wandered many miles from their home. Such heaps of glacial débris are called "terminal moraines." But it may be asked, Are the stones found in these moraines *all* to be accounted for in this way?—an interesting question, and one upon which geologists do not seem to be at present quite agreed. Can we not conceive that the weight and pressure of a descending glacier are sufficient to break off many protruding portions of the rocky bed over which it flows, and then to drag them along with it? This seems reasonable, and is maintained by some geologists, with whom we are inclined to agree. Let us therefore consider the materials of which moraines are composed to be derived partly from the rocks beneath and partly from those above the glacier. But whatever their origin, such materials must all inevitably find their way to the end of the glacier. The work of transportation is then taken up by the stream which always flows from the end of a glacier. Such streams are in summer time laden with fine

sediment, which gives them a milky, turbid appearance. In this way glaciers give rise to rivers.

Let us now consider the erosive work of glaciers. We have already pointed out that rock fragments become embedded in the ice. There they are held fast as in a vice. Now these are the tools with which a glacier does its work. It must be granted that the downward movement of a great mass of ice is irresistible, and consequently that as the moving glacier slowly creeps along it, must inevitably cause the stones which it thus holds to grind over the surface of the rock. It is easy to imagine the effects of this grinding action. If sand-paper, rubbed for a minute or two over wood, wears down and smooths its surface, what must be the result of all these stones, together with mud and sand, grinding over the rocky bed over which a glacier flows? It has been proved by numerous observations in Switzerland and elsewhere that glaciers exert a considerable power of erosion and wear down the rocks over which they slowly creep, at the same time scratching and polishing their surfaces. The Swiss glaciers formerly extended very far beyond their present limits; and it is by examining the rocks over which they once flowed that geologists have been able to prove the great erosive power of glaciers. Of course it is not the ice which does this work, but the stones which it contains. Ice by itself is too soft to affect hard rock, but give it stones to work with and its erosive power becomes truly wonderful. The stones of which moraines are composed are generally not quite angular or sharp-cornered, but have their

sides and angles slightly rounded off. The lower surface is often considerably worn down and scratched. As a rule the scratches, or striæ, as geologists call them, are round, roughly parallel to each other, but sometimes two sets of striæ may be seen crossing each other at an angle. But the largest and most remarkable striæ are to be seen on the surfaces of rocks over which glaciers once flowed. These run parallel to each other, and are of various sizes, from tiny scratches up to big grooves an inch or more in depth.

The stream which takes its rise from the end of a glacier frequently issues out of an arcade or cavern of vast proportions; but it is dangerous to venture far into these vaults of ice, for every now and then blocks break away, with a fearful crash, into the stream below. But the lovely effects of light due to reflections of sunshine passing through transparent edges of ice are very tempting. Among the Alps during a summer day a good deal of ice is melted, and the water thus set free by the sun's heat flows along in brooks over the glacier until it reaches a *crevasse*, where, tumbling down in a waterfall, it is lost in the depths below. The effect of such a fall on the rocky floor is very similar to that of a Highland waterfall. It gradually drills out a deep "pot-hole" like a well. On the ice-worn surfaces of Norway such holes frequently occur, and are called "giant's kettles." They still contain the stones and mud which by a constant gyratory movement imparted by the water drilled out these curious holes.

One effect of glaciers is very conspicuous, namely

the rounding of the rocks over which they once flowed. This is often seen in Switzerland. The corners and angles of projecting pieces of rock in a valley have been worn away until the once rugged outline has become wavy and round, so much so as to produce more or less resemblance to the back of a sheep lying down. Hence the name *roches moutonnées*, by which rocks of this shape are known. Such surfaces, when not much weathered, often show striæ running in one direction. It is not difficult to tell the direction from which the ice came; for one side, the sheltered or "lee-side," is generally less worn down than that which directly faced the moving ice, and is often rugged and free from glacial striæ. Thus on looking *down* a Scotch Highland valley *roches moutonnées* are often seen in great numbers; but on turning round and looking *up* the valley, we may not see them at all, because that is not the direction in which the ice flowed.

There cannot be much doubt that a good deal of water circulates beneath glaciers; and if so, it must have a considerable share in producing the erosive effects to which we have already alluded. Some geologists, however, maintain that glaciers have little or no power to erode the rocks over which they flow. This strange conclusion they arrive at because *at the end of a glacier* very little, if any, erosion seems to be effected. Unfortunately our direct knowledge of the effects of glaciers is limited to observations made at their terminations. From the nature of the case this must be so; but the end of a glacier is *not* the place where one would expect to

find erosion going on any more than at the end of a river. The glacier has *then* done its work. Its velocity and erosive power are much less than in the higher and steeper parts of its course. To gain a clear idea of what ice can do in this direction it is necessary to go to some fairly high mountain region from which all the ice has now gone, and to study there its former effects. Those who do this are generally convinced by the numerous evidences of considerable erosion which they meet with; and in this way some geologists have been led to entirely alter their views.

We must now say a word about icebergs as geological agents. Now all icebergs are portions of ice which have broken away from a glacier when it came down to the sea, or of some great ice-sheet such as are seen in Arctic and Antarctic regions.

An Arctic glacier, on descending from high ground to the sea, extends some way into the water, but presently, on account of its floating power and the rise and fall of the tides, breaks off into vast icebergs, which come drifting southwards with a cold marine current which washes the shores of Labrador. These bergs (or towers, as their name implies) are often of enormous size, sometimes rising 200 or 300 feet above the water; but the greater part is unseen, being sunk in the water. Probably some have a total thickness of over 2000 feet. The lower parts of an iceberg contain a certain amount of débris in the form of stones, mud, etc., and as they gradually melt on their southward journey these materials must finally be strewn over

the bed of the sea and be more or less stratified. We shall presently have to consider whether certain glacial deposits may possibly have been formed in this kind of way. In Arctic sounds and bays the littoral waters freeze along the shores and form a cake of ice. This shelf is known as the "ice-foot," and since it bears much débris from the coast, both on its surface and embedded in the under parts, it must also on breaking loose and drifting away deposit a good deal of glacial detritus on the sea-floor, so that we must bear this in mind as a possible explanation of certain drifts. This is a very brief outline of the geological work of ice. The reader who desires more information on this subject should consult a good text-book of physical geology, or, better still, travel in a land of glaciers such as Norway or Switzerland, and keep his eyes open to observe the effects they have produced on the rocks.

Let us now return to our own country in order to take a brief survey of its glacial deposits, and endeavour to read the very interesting story of the records of the Great Ice Age in Britain.

The evidences with which we have to deal are of different kinds. *First*, there are the striated or more or less worn stones found among the old terminal moraines of glaciers, which once flowed down valleys in Wales, Ireland, and Scotland. Such striated stones are also found in the "Till" or "Boulder Clay"—a very remarkable and somewhat perplexing deposit forming the lowest division of the glacial drifts, and which is now believed to have been formed beneath a great series of glaciers uniting to

make up a great continental ice-sheet. But of this we shall have more to say presently. *Secondly*, the worn and rounded aspect of the rocks in our mountain districts, especially in Scotland, the valleys, hillsides, and often the mountains themselves, presenting in certain directions gentle undulations which are very characteristic of ice action. The numerous "erratic boulders" which afford so much information with regard to the movements of the ice-sheet in Great Britain may be included under this head. Professor A. Geikie says: "Such 'erratics' not only abound in the Swiss valleys, but cross the great plain of Switzerland, and appear in numbers high upon the flanks of the Jura. Since the latter mountains consist chiefly of limestone, and the blocks are of various crystalline rocks belonging to the higher parts of the Alps, the proof of transport is irrefragable. Thousands of them form a great belt of boulders extending for miles at an average height of 800 feet above the Lake of Neufchâtel." In the same way "erratics" in Great Britain serve to record the movements of various glaciers from the mountain masses of Wales and Scotland, Cumberland, and other districts. *Thirdly*, the glacial deposits themselves. First comes the Till or Boulder Clay, the lowest division of the series, resting on ice-worn surfaces of the low ground. The sands, gravels, moraines, and erratic blocks may be considered to belong to later phases of the Ice Age. The glacial deposits of Scotland and the northern districts of England differ considerably from those of the midland and southern counties, but we cannot attempt

a detailed description here. The relations of the "drifts" in these separate regions to each other are not yet determined. And *lastly*, we have the evidence derived from the remains of plants and animals found in glacial deposits, most of which are undoubtedly of Arctic species, and must have migrated from northern latitudes as the climate began to get colder. Thus we find a great mass of evidence all pointing in the same direction, which, if brought forward in detail before a court, would occupy a learned judge for a considerable time—perhaps as long as the famous Tichborne trial. And we venture to think that the evidence would be more easily understood and lead to a clearer verdict than sometimes terminates a celebrated trial!

It will now be necessary to look into the evidence a little more closely. In certain parts of Scotland the hard rocks over which glaciers once flowed may be seen presenting the appearance of a series of smooth bosses or waves, which at once catch the eye of a geologist accustomed to notice glacial phenomenon. These are the characteristic *roches moutonnées* of Switzerland, to which we have already alluded as the work of glacier-ice. In many cases, as where a layer of soil or moss covers the surface, the polished and striated rock may be seen looking almost as fresh as if the glacier had vanished but yesterday.

The striæ vary much in depth, from mere scratches to deep grooves or ruts. Evidence of this kind is, when seen, very striking, and carries conviction even to those who have never studied the

subject before. Good examples occur in the Pass of Llanberis, where a trained eye can also detect the moraines of old Snowdonian glaciers (see Fig. 21).

But to a geologist the very outlines of the hills and mountains in a glaciated district tell the same story. For though often presenting steep precipices, cliffs, and other features which have been carved out by "rain and rivers," yet one may see the broad undulating surfaces which undoubtedly were planed down by the action of ice. Numerous examples occur in Scotland.

We must, however, pass on to the Till or Boulder Clay. This deposit is found all over the low grounds of North Germany, Denmark, Holland, Scandinavia, and much of England and Ireland. It varies greatly in thickness, and may even be traced up some of the valleys. Generally it is a stiff stony clay and unstratified, but may sometimes contain layers of sand, laminated clays, and even peat. It is frequently arranged in long parallel ridges indicating the direction in which the ice flowed, that is down the valleys and broad plains. These intercalated beds in the Boulder Clay are very remarkable, and present interesting problems concerning which geologists are not agreed. With regard to the Till itself there is not so much difference of opinion, and most authorities now consider it as the *moraine profonde* or ground-moraine of a continental ice-sheet. The reader will now be in a position to understand how this came about. It must have been formed very much in the same way as the moraines of the old Swiss glaciers already alluded to. Speaking of the Scotch Boulder

Clay, Professor James Geikie says: "In many cases, however, we find, instead of all this planing and polishing, only a jumbled accumulation of large blocks and broken débris under the Till. The rock-bed has been smashed and crushed, and large masses have been pushed out of place, the boulder-clay often appearing tightly rammed between the blocks . . . and one can see that the dislocated fragments have been dragged along in the same direction as that followed by the trend of the glacial striæ and 'drums' of Till in the same neighbourhood" (*Prehistoric Europe*). Drums are long broad ridges of sand and gravel, supposed to be glacial, which trend in the same direction as the valleys in which they occur.

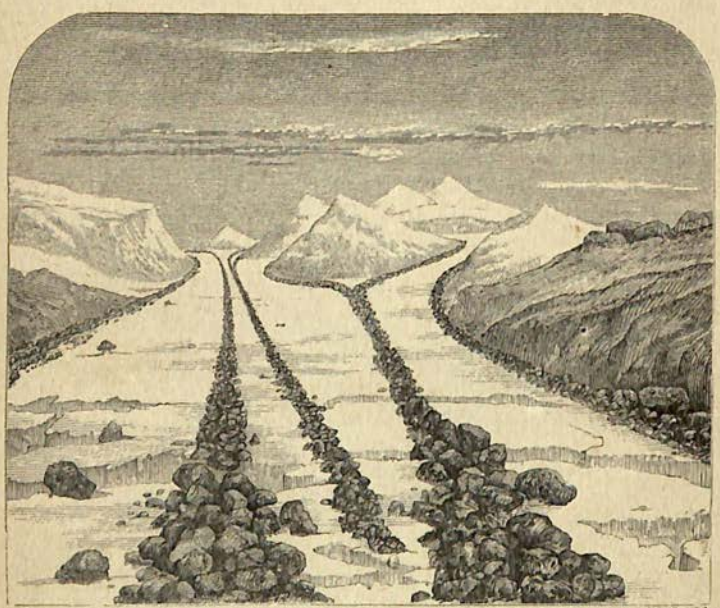
One conspicuous feature about the Till is that it partakes largely of the local character of the rocks in each district where it occurs. Thus over the Old Red Sandstone its colour is red, and over the Carboniferous rocks it is dark. The included stones also are mostly of local origin. It is probable that portions of the Till represent old soils and rock debris which had been accumulating before the Glacial period began. But to what extent this may be the case it is impossible to say. Speaking generally, however, the Boulder Clay represents the erosive action of glaciers during the great Ice Age. But *all* the stones are not of local origin. A certain percentage are found to have come from a distance, for they are not of the same mineral composition as the local rocks. In many cases it is easy to ascertain where the stones came from by noting the situation of rocks of a similar composition, and also from the direction

of flow indicated by rock striæ—as in the case of the Swiss erratics now on the Jura. Professor A. Geikie remarks that in the valley of the Forth, while most of the fragments included in the Boulder Clay are from surrounding Carboniferous rocks, from 5 to 20 per cent have come eastward from the Old Red Sandstone range of the Ochil Hills—a distance of twenty-five to thirty miles; while 2 to 5 per cent are fragments of Highland rocks which must have come from the high grounds at least fifty miles away to the north-west.

Of late years a large number of zealous observers have studied the directions of glacial striæ in different places, and their relations to the present features of the ground. The results when mapped down are very interesting, and have afforded much valuable information with regard to the movements of the ice-sheet. The directions taken by erratic blocks serve to supplement this evidence. One of the chief discoveries thus made is that each main mass of high ground in Britain served as a centre whence the ice flowed down in all directions. Thus we find that the Grampians, Southern Uplands of Scotland, the hills of the Lake District and of Wales all supported their own glaciers, and formed centres of dispersion from which erratic blocks were carried for considerable distances. Again, by observing the heights up to which striæ and other signs of glaciation can be observed, it has been found possible to estimate the former thickness of the Scotch ice-sheet. Now many mountains in the Highlands have evidently been

"glaciated" up to a height of 3000 feet or more. In this way it has been proved that ice from the Grampians went across the broad plains of Perthshire, filling them up to a depth of at least 2000 feet. The Ochil Hills are twelve miles distant from

Fig. 21.



Glacier of the Pass of Llanberis (restored). Snowdon in the distance.

the Highlands, and attain a height of 2352 feet; yet even a barrier such as this failed to stop the ice in its course southwards, for there is evidence to show that it went right over them. On the low grounds we find that glaciers met from various quarters,

directed by the slope of the higher ground, and then flowed together along some broad valley, such as that of the Forth or the Clyde. This is just what the rivers and their tributaries do at the present time, and so we are warranted in concluding that in those days the present valleys existed, and the features of the country were pretty much the same as they are now. On the Norwegian coasts the striæ run westwards and north-westwards, and it is believed that the Norwegian ice-sheet, extending over what is now the bed of the North Sea, met the glaciers flowing east from the northern Highlands, and thus was forced to change its course to the north-west. In this way the two ice-currents would pass on to an old coast-line (now sunk) somewhere below the Faroe Islands. But the main mass of Highland ice flowing east, meeting with the Norwegian stream, turned it and coalesced with it, so that both together flowed south and south-west down what is now the North Sea. Great Britain at this time was joined both to the Continent and to Norway. In the latter country the ice-sheet was probably not far off 7000 feet in thickness.

In England the Pennine chain supported local glaciers and formed a centre from which ice radiated outwards. Certain well-known Norwegian rocks have been found in the Yorkshire Boulder Clay, but none in Scotland, because the Highland ice-stream was powerful enough to deflect that which came from Norway. We have already spoken of the Boulder Clay as the product of land-ice. In the low grounds near coasts the Boulder Clay sometimes contains

marine shells and evidences suggestive of floating ice, either in the form of icebergs or of an ice-foot, as previously explained. That at one time during the Glacial period a good deal of land was submerged below the sea may be considered as proved. This took place after the time of most intense cold. Glaciers must have invaded the sea and partly filled it with floating icebergs. North Wales sank to a depth of 1350 feet. This is proved beyond a doubt by a terrace with marine shells on Moel Tryfaen.

At times during the Ice-Age a temporary lull seems to have taken place. For we find, curiously mixed up with Boulder Clay, beds of sand, gravel, clay, or peat. Some of these "interglacial deposits" contain remains of the mammoth, great Irish deer, horse, bear, and other animals, together with remains of trees such as oak, birch, etc. Facts like these point to a temporary change of climate—like a thaw coming in the middle of a frost and then giving way to frost again. It would seem then that in the low-lands the ice-sheet melted and a comparatively warm climate prevailed, so that the land was clothed with vegetation, though doubtless in the Highlands the snow-fields still remained. During these intervals the climate became so mild that animals of a southern type came into Europe and even Britain (there being then no English Channel or North Sea). This is proved by the bones of porcupines, leopards, African lynxs, lions, hyænas, elephants, and hippopotami.

It is curious to find the remains of animals such as these, which certainly at the present day prefer

a warmer climate than that of Britain, occurring in glacial deposits.

But this state of things did not last very long. After a partial submergence the land rose again, and Arctic conditions of climate prevailed once more in full force. Elevation of the land increased the snowfall, and thus the supply of ice would be largely augmented, and the lowlands once more covered by a *Mer de glace*. The Boulder Clay itself does not contain bones, but only occasional marine shells, some of which were probably pushed forward out of the sea-bed by moving ice, for they are often broken and fragmentary. But certain other facts testify to submergence.

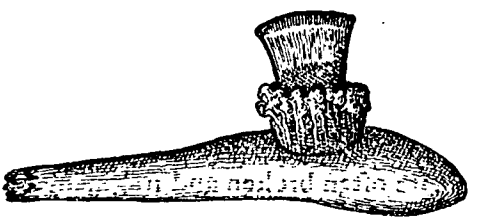
The second period of intense cold is recorded by the Upper Boulder Clay of England.

The later deposits of the Glacial period, stratified sands and gravels and deposits formed by rivers, such as are found in old "river terraces" considerably above the present river-courses, are generally supposed to have been formed after the retreat of the ice-sheet; but perhaps they may be as old as the Boulder Clay of the north. It is, as before remarked, extremely difficult to correlate the various deposits of the Pleistocene period. There are also some interesting cave-deposits containing many bones of mammals, the relation of which to glacial drifts is still a matter of opinion; but it is possible that they may be records of the Great Ice-Age, or, as geologists say, *inter-glacial*.

The river-gravels, which probably are of the same age as the cave-deposits, contain the first traces of the appearance of man on this planet. These, as

every one knows, take the form of rude flint and stone implements chipped out by the hand of primeval man for purposes of defence and utility. Hundreds of these stone implements—axes, hammers, spear-heads, arrow-heads, etc.—have been discovered, and may be seen in our museums. The most complete and perfectly arranged collection is the one at the Salisbury Museum. Many bones of quadrupeds are associated with the flint implements both in cave and river gravels. And the same curious intermingling of northern and southern forms is also noticed. Hence there is some reason to conclude that man lived in Britain and the Continent during part of the Great Ice-Age. At any rate it is proved beyond a doubt that the great mammoth or woolly elephant (which flourished on the plains of Europe and Britain and is now extinct) was contemporary with man. For the cave-men of the south of France saw him and carved out a sketch of him on mammoth ivory representing his long tusks and shaggy coat. They also drew other animals on reindeers' antlers.

Fig. 22.

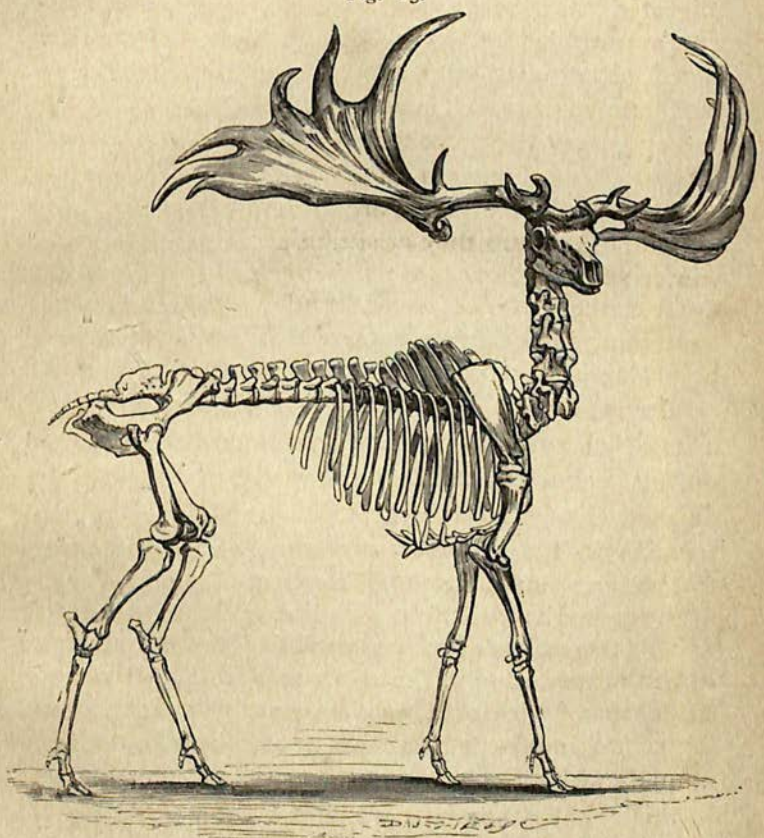


Modern Flint Implement attached to a Wooden Handle, to be used as a Hatchet.

Supposing that the older river-gravels and cave-deposits were formed during the Great Ice-Age, let us see what kinds of quadrupeds inhabited Britain

then. These have yielded many bones, most of which have been determined. We thus learn that besides

Fig. 23.



The Great Irish Elk (*Megaceros Hibernicus*).

the mammoth there was another species of elephant (*Elephas antiquus*), three species of rhinoceros, the

cave-bear, Arctic fox, reindeer, Arctic and Norwegian lemming, marmot, musk-sheep, etc.

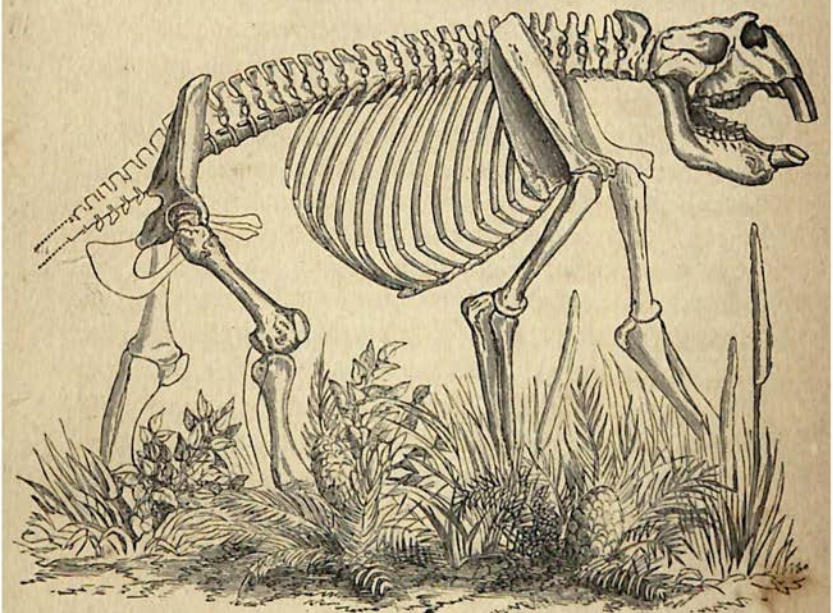
During the Glacial period Arctic plants also migrated southwards, and when a warmer climate finally prevailed (after the disappearance of the ice-sheet), either died out or found a retreat in the high mountain regions. Thus we still find on the Alps, and even on the mountains of Wales and Scotland, plants whose home is in higher latitudes. Many well-known Alpine plants are found in the Highlands of Scotland, where they are quite at home among the winter snows.

A later series of sands and river-gravels, also containing flint implements, which occur at a less height above the present river-courses, testify to the passing away of the Great Ice-Age and the return of a mild climate. The flint and stone implements of this period (Neolithic) are polished and highly finished, showing advance in art. The animal remains in these gravels are mostly such as belong to creatures now inhabiting Europe. Primitive man in Europe was probably a hunter clad in skins, of small stature, and much resembling the Esquimaux of the present day. Certain caves in England and Wales have yielded a very interesting collection of bones, telling us of the existence here of many animals which are either extinct or no longer known in this country, amongst which are the following :—

Hippopotamus	Glutton	Brown Bear
Reindeer	Cave Lion	Leopard
Irish Elk	Bison	Wild Cat
Grisly Bear	Beaver	

But lions and leopards seem to have been absent from Ireland; and this fact may account for the abundance of deer at that time. The Irish elk (Fig. 23) was a gigantic creature, its noble antlers

Fig. 24.



Skeleton of Diprotodon, a gigantic extinct Marsupial.

measuring 8 feet from tip to tip. Its remains are often found in gravel at the base of the peat-beds.

The bone-caves of Australia have yielded remains of some gigantic marsupials, which at the present day are represented by species of far less size.

One of these, *Diprotodon*, was a huge vegetable-

feeder, with a skull 3 feet in length, and in some respects like the wombats of the present day.

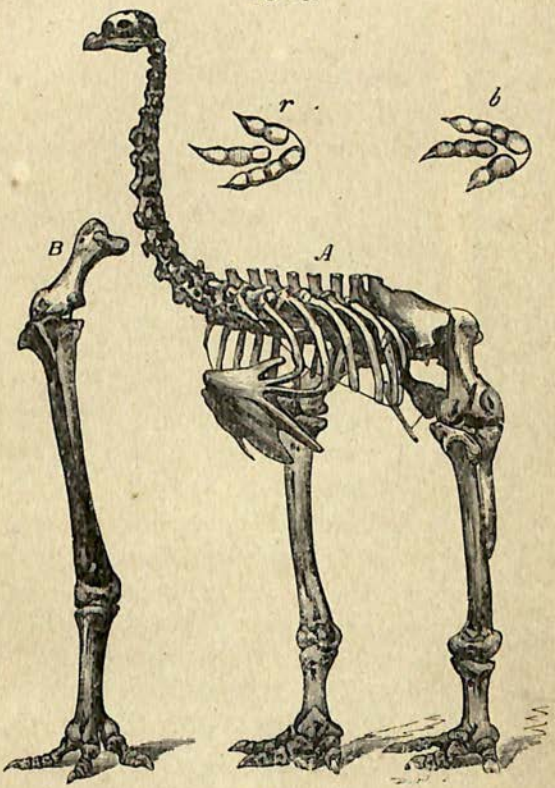
Fig. 24 is a restoration by Professer Owen of this most remarkable extinct marsupial. Its remains have been found both in the drift-deposits and in the caves of Australia. *Thylacoleo* was probably a huge carnivorous marsupial. Other forms have been found which resemble Kangaroo-rats.

Passing on to New Zealand, we find in the Pleistocene deposits of that island the remains of some enormous wingless birds, which evidently are related to the ostrich and other "running birds." It is a significant fact that New Zealand is at the present time inhabited by a small wingless bird, the *Apteryx*, which probably is a survival from the earlier and larger forms. Of these the most interesting is the *Dinornis* or *Moa-bird. Dinornis giganteus* must have been a very formidable creature at least 10 feet high. Fig. 25 shows a complete skeleton of *D. elephantopus* and the leg of *D. giganteus; b* and *r* are footprints of these birds. But in Madagascar a still larger bird existed at some time during the this period, namely the *Æpiornis*. Eggs have been found with its bones, and these are 14 inches in diameter (about equal to 148 hen's eggs). The now extinct Dodo from the Mauritius was a bird of this kind, but very small in comparison.

As Australia, New Zealand, and Madagascar were, within geologically recent times, the home of monstrous marsupials and gigantic birds, so South America in the Pleistocene period was inhabited by

some wonderful sloths and armadillos of much greater size than those species which live there at

Fig. 25.

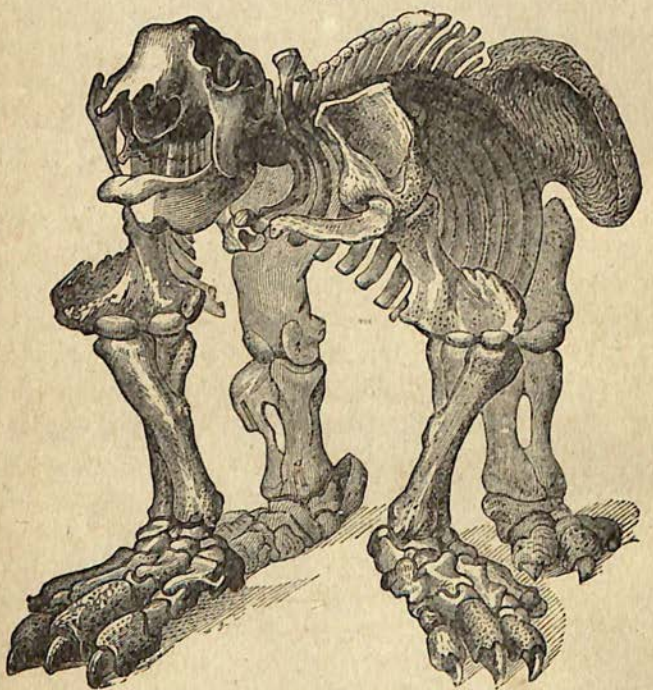


A, *Dinornis elephantopus*. *B*, Leg-bones of *Dinornis giganteus*. *b*, *r*, Impressions called Ornithichnites.

the present day. We must therefore say a word about these fossil edentates. The *Edentata* belong to the lowest order of placental mammals. The

name, given by Cuvier, seems to imply an entire absence of teeth, as indeed is literally the case with some species; but in others teeth do exist, though

Fig. 26.



Megatherium, a Colossal Sloth-like Edentate from Pleistocene Deposits of South America, length about 18 feet.

of a peculiar structure. They all, however, agree in having no front or incisor teeth (but one of the armadillos makes the inevitable "exception" which "proves the rule"). They have long claws, and their skins are covered either with long plates, or else with

scales. The ant-eaters form another group of edentates. Now these three living groups of sloths, armadillos, and ant-eaters were well represented in South America during Pleistocene times. It was the illustrious Charles Darwin who first perceived and interpreted the meaning of this close connection between living and extinct forms belonging to the same geographical area. His theory of descent with modification, or in other words evolution, solved the mystery, and showed that the surviving forms of the present are lineal descendants of those whose remains we find embedded in superficial deposits.

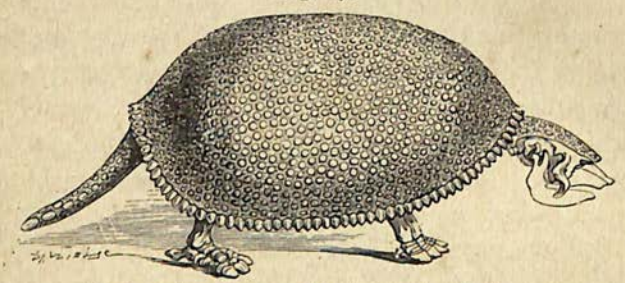
But in the case of these edentates, the marsupials from Australia, and the birds from New Zealand, the progress, instead of being *upwards*, has been *downwards;* and creatures that were once so colossal in size have dwindled down to much more moderate dimensions. Thus the sloths were then represented by such gigantic forms as *Megatherium, Mylodon, and Megalonyx.*

Fig. 26 shows the skeleton of a great *Megatherium.* Unlike living sloths, which spend their lives hanging on to branches of trees, this creature was terrestrial, and stood up on its hind legs to make its meals off the leaves of trees. In this position the huge tail would be a powerful support.

Glyptodon was a gigantic armadillo (see Fig. 27). The carapace or shield which covers the body measures 7 feet in length and 9 feet across, and the total length of the creature from head to tail was 11 feet 6 inches. It could not roll itself up into the

form of a ball, as the living armadillos do when attacked, because its shield is composed of bony plates all closely united into a solid buckler. But

Fig. 27.



Extinct gigantic Armadillo (*Glyptodon clavipes*).

with such armour it could stand its ground against all comers.

Mr. A. Russell Wallace, referring to the strange extinction of so many large mammalian types within a comparatively short time, says: "We live in a zoologically impoverished world, from which all the largest, and fiercest, and strongest forms have recently disappeared." How are we to explain this remarkable fact. Mr. Wallace would attribute it to the low temperature prevailing during the Glacial period. But it is doubtful how far this explanation would apply to all cases—the mammoth, for instance, with its shaggy coat to keep it warm; and it seems more reasonable to suppose that MAN, with his superior brain, was more than a match for even the most formidable mammals, and that thus the types we have been describing succumbed in the "struggle for existence."

Into the question of the possible cause or causes, of the remarkable change in climate which brought about the Ice-Age we cannot enter here, as it would require a chapter to itself. Astronomical explanations have been brought forward, but we are more inclined to agree with those who prefer to explain the facts by purely geographical changes. A different distribution of land and water, changing the directions of ocean-currents, and powerfully affecting the distribution of atmospheric pressure, will account for a great deal.

The records of the later Stone Age pass insensibly into those of the human period. At this stage it is time for the geologist to lay down his pen and allow the antiquarian and historian to take up the story of the ages.

INDEX

ACROGENS, 115, 119
Æpiornis, 278
Agents, geological, list of, 23
Age of rocks, how determined, 61; of cycads, 152, 200; of mammals, 238; of reptiles, 160
Agglomerate, 34
Ammonites, 62, 232; zones of, 203
Amphibians, 125, 157
Amplexus, 96
Anchitherium, 245
Animals, geological action of 27
Annelida, 56, 120
Anomodonts, 167
Anoplotherium, 246
Anthracotherium, 246
Anticline, 52, 64, 137
Apteryx, 278
Araucarian pines, 200
Archæan rocks, how formed, 33
Arctic flora, 266, 276; ice-sheet, 255; glaciers, 263
Archæopteryx, 214
Arenig slates, 51
Ashes, volcanic, 66
Athyris, 96
Atlantic Ocean, soundings of, 98, 185, 229; fauna of, 227, 228
Atlantosaurus, 210
Atmospheric influences, 258
Australia, fauna and flora of, 197, 216; bone-caves of, 277

BALL, Professor, on tides, 13
Barrier Reef, Great, 189
Basaltic rocks, 83
Basin of Mississippi, 133; Hampshire, 240; Paris, 240
Bath Oolites 177
Bear, brown, 276
Beech, fossil, 232
Belemnite, 155, 196, 203, 232, 242
Belodon, 164
Birds, gigantic, 278; first record of, 214; ancestors of, 174, 211, 236
Bison, 276
Bone-bed, 155
Boulder Clay, 264, 265, 267, 271
Boulders, erratic, 259, 265, 268, 269
Bovey Tracey, Miocene deposits of, 247
Break, the physical, 44; the organic, 48, 238
Breccia, 81, 148
Brontosaurus, 210
Brontotherium, 249
Buckland, Dr., 187
Bunter rocks, 147
Butterfly, earliest known, 201; fossil, 248

CAINOZOIC era, 28, 238
Calamites, 116
Cambridge Greensand, 219
Cambrian rocks, 45
Camel, fossil, 249, 251
Cannel coal, 114

Carboniferous Limestone, 91, 120
Carpathians, 241
Carpenter, Dr., see Eozoon
Catastrophic theories, 19
Cave-men, 274
Cephalopoda, 187, 202, 232
Ceratosaurus, 213
Cetiosaurus, 212
Chalk, origin of, 98, 223; fauna of, 232; flora of, 232; depth of Chalk sea, 227; climate of Chalk period, 231; Dr. Sorby on, 223
Challenger, H.M.S., expedition of, 185, 229
Cheirotherium, 157
Chloritic sand, 222
Classification of Cambrian and Silurian rocks, 49; of Cainozoic rocks, 239; of plants, 115; of mammals, 243; of reptiles, 161, 205; of dinosaurs, 209
Clay, Kimmeridge, 179; Oxford, 179; Weald, 218; Red, 229; London, 241
Cleavage, nature of, 65
Clock, geological, 154
Coal, origin of, 109; structure of coal-fields, 138; coal forests, 119; fauna of Coal period, 121
Coccosteus, 89
Cockroaches in coal, 123
Cœluria, 211
Colossochelys, 248
Colour of Old Red Sandstone explained, 76, 146
Compsognathus, 211
Conifers, 86, 119, 151, 197, 232
Conglomerates in Cambrian rocks, 45; in Old Red Sandstone, 79; in New Red Sandstone, 145, 148
Contortions of strata, 35
Contraction, cause of earth-movements, 36
Cooling of the earth, 37
Coral Rag, 179
Coral-reefs, 70, 95, 189
Crabs, fossil, 201
Crags, 250
Cretaceous rocks, 217
Crickets, fossil, 123
Crinoids, see Encrinites
Crocodiles, fossil, 164, 174, 233
Cryptogams, 115
Cuvier, 244
Cyathophyllum, 96
Cycads, 151, 197, 200, 232, 242
Cynodraco, 168
Cypris, 193

DANA, Dr., 95, 191
Darwin, on coral-reefs, 95
Dawson, Professor, 42, 123
Day, length of, 13
Density of the earth, 6
Denudation, 132, 135, 145
Devonian rocks, 90
Dicotyledons, 115
Dinornis, 278
Dinosauria, 169, 205, 209, 234
Dinotherium, 249, 251
Diprotodon, 277
Dodo, 278
Dryopithecus, 249
Dust, volcanic, 229
Dykes, volcanic, 67

ECHINODERMS, fossil, 201
Edentata, fossil, 244, 279
Eggs of trilobites, 58; of æpiornis, 278
Elephants, fossil, 246, 274
Elevation of mountain chains, 36, 140
Encrinites, 69, 93, 155, 188, 201
Endogens, 115
Eocene rocks, 239; fauna of period, 242; flora of, 242
Eozoon, 42
Equisetaceæ, 115
Eras, geological, 28, 44, 237
Erratics, see Boulders
Eruptions, volcanic, 66, 81
Estuarine conditions, 193
Euplectella, 226
Eurypteridæ, 71
Evolution, 119, 125, 170, 174, 211, 246, 281

Extinction of reptiles, 174; of Cretaceous animals, 242; of large mammals, 282

FACIES of flora, 152
Faults, 52
Feathers of archæopteryx, 214
Ferns, fossil, 115
Firs, see Conifers
Fishes, fossil, 71, 87, 124, 155
Flies, see May-flies
Flint, origin of, 225
Footprints of dinosaurs, 171; of labyrinthodon, 157; of reptiles, 150; of turtles, 162; of iguanodon, 234; of palæotherium, 244
Foraminifera, 43, 99, 188
Forests of Coal period, 106
Forest-bed, 250
Fucoids, 69

GANOID fishes, 72, 89, 124, 204
Gar-pike, 72
Gault, 219, 222
Geikie, Professor A., on Old Red Sandstone lakes, 84; on coral-reefs, 189; on erratics, 265
Geography of Old Red Sandstone period, 84; of Carboniferous Limestone period, 102; of New Red Sandstone period, 148; of Jurassic period, 195; of Chalk period, 230; of Eocene period, 241; of Miocene period, 248; of Pliocene period, 250; of Pleistocene period, 271, 272
Geological time, 14, 136
"Giant's kettles," 261
Glace, Mer de, 257
Glaciers, geological work of, 80; Forbes on motion of, 257; transportation by, 258, 265
Glacial drifts, 254, 266; moraines, 80, 149; *moraine profonde*, 267
Glacial period, see Ice Age
Globigerina ooze in Atlantic, 99, 223
Glyptodon, 282
Granite, 83
Graphite in Laurentian rocks, 32, 40
Graptolites, 69
Gravels, river, flint implements in, 274
Greenland ice-sheet, 255
Greensand, see Cambridge Greensand

HALITHERIUM, 244
Hall's experiments on limestone, 96
Hamites, 233
Heat, effects of, 27, 33, 96
Hesperornis, 236
Heterocercal tails, 155
Highlands of Scotland, 32, 231, 269, 271
Himalayas, 140
Hipparion, 245
Hippopotamus, 251
Horizons, 203
Horse, ancestors of, 245
Huggins, Dr., on star spectra, 6
Hutton, 19, 31
Hydrocarbons, 40
Hydrogen in stars and sun, 6
Hyracotherium, 245

ICE Age, 252; cause of, 282
Icebergs, 263
Ice, geological work of, 256
Ice-sheet, 252, 255, 267, 271
Ichthyornis, 236
Ichthyosaurus, 205
Iguanodon, 171, 234
Imperfection of the record, 1
Implements, see Gravels
Increase of temperature below ground, 8
Inoceramus, 223
Insects, fossil, 123, 196, 248
Interglacial beds, 272

JURA mountains, 178
Jurassic rocks, 177

KANGAROO-RATS, 278
Keuper rocks, 147, 150
Kimmeridge Clay, see Clay
King-crab, 57

LABYRINTHODON, 125, 157
Lakes of Old Red Sandstone, see Old Red Sandstone
Land-plants, 85, 148
Land-snails, 123
Laurentian rocks, 40
Lava, 67, 81
Leopard, 276
Lepidodendra, 116, 151
Lias, meaning of, 180
Life, succession of, see Evolution
Limestones, origin of, 41, 70, 93, 188, 223
Lingula flags, 51
Lingulella, 58
Lioostrotion, 96
Living matter, effects of, 26
Lizards, fossil, 162, 163, 204
London Clay, 241
Longmynd group, 50
Lophiodon, 248
Lycopods, 69, 115
Lyell, Sir Charles, 21, 131, 185

MACHAIRODUS, 251
Madrepores, 70, see Corals
Mammals, first appearance of, 174, see Extinction
Man, geological effects of, 26
Mammoth, 272, 274
Marble, origin of, 35, 96
Marsupials, 216, 243, 277
Mastodon, 249
May-flies, 123, 196, 201
Megaceros, 276
Mendip Hills, 135, 137
Menevian beds, 50
Mesozoic era, 154, 160, 200
Metals in the earth, 6
Metamorphic rocks, 34, 42
Metamorphism, 35
Meteorites, 7
Microlestes, 175
Microscopic section of coal, Fig. 8, p. 113
Miller, Hugh, 87
Millstone Grit, 120
Miocene period, 239
"Missing links," 156, 173, 246
Mississippi, rate of erosion by, 134
Mollusca, 58, 96
Moon, birth of, 11; tides caused by, 13
Moraines, see Glacial period
Mud-fish, 156
Mull, leaf-bed of, 247

NANSEN, Professor, 255
Nebular theory, 7
Neocomian rocks, 219
New Red Sandstone, 145; climate of period, 157; fauna of, 155
Nipadites, 241
Nummulitic limestone, 241

OAK, fossil, 232
Oceanic basins, permanence of, 230
Oceanic deposits, 99
Odontopteryx, 242
Oldhamia, 55
Old Red Sandstone, 74; lakes of period, 85; fishes of, 88; climate of, see Geography; fauna of, 87; flora of, 85
Oolite, see Bath
Oolitic structure, 181, 192
Ooze, Atlantic, 99, 229
Opossums, 243
Ordovician rocks, 50
Organically formed rocks, 41, 70, 93, 223
Organic break, 48, 238
Orthoceras, 58
Oxford Clay, see Clay

PALÆOZOIC era, 28, 237
Palm, fossil, see Nipadites
Paradoxides, 57
Paris basin, see Basin
Peat, 113
Pennine Chain, 140
Permian rocks, 145; classification of, 146
Phosphatic nodules, 219
Placoid fishes, 72, 152, 204
Pleistocene period, 253
Plesiosaurus, 165
Pliocene period, 249

Polycistinæ, 224
Polyzoa, 202
Portland limestone, 179
Pot-holes, 261
Pre-Cambrian rocks, see Archæan
Primary era, 45, 62
Progress, law of upward, 69, 119, 124, 153, 237
Protorosaurus, 162
Pteranodon, 235
Pterichthys, 89
Pterodactyls or Pterosauria, 207, 234
Purbeck marble, 193; strata, 198
Pyrenees, 241

QUARTZ, in Granite, 32
Quartz rock, 34

RADIOLARIA, see Polycistinæ
Rain, action of, 25
Rain-drops, marks of, 150
Red Clay, see Clay
Regelation theory, see Tyndall
Reindeer, 276
Reptiles, living orders of, 161; extinct orders of, 161, 205; of New Red Sandstone period, 159; of Jurassic period, 199; of Cretaceous period, 233; of Cainozoic era, 242; approach to bird type, 169; flying reptiles, see Pterodactyls; origin of, 124
Rhætic strata, 182
Rhinoceros, 251
Ripple-marks, 59
Rivers, action of, 25
Roches moutonnées, 266

SALISBURY Museum, 274
Salt-beds, 150
Sandstone, Old Red, 74; New Red, 145
Saurians, 205
Scandinavian boulders, 271
Scenery of Mountain Limestone, 91; of Old Red Sandstone, 74; of Palæozoic rocks, 179
Schists, crystalline, 33
Scorpions, fossil, 123
Sea, geological work of, 26
Sea-serpents, 235
Sea-urchins, 55
Secondary era, 62
Sedgwick, Professor, 49
Seeley, Professor, on Pterodactyls, 209
Serpents, fossil, 233
Sigillaria, 118
Silica, 226
Silurian period, 28, 63; fauna of, 69; volcanic rocks of, 68
Sirius, 7
Sivatherium, 249
Smith, William, 63, 181
Snowdon, 67, 267
Snow-fields, 256
Solenhofen stone, 201
Sorby, Dr., on chalk, 100
St. Cassian beds, 155
Species, origin of, 120
Spectra of stars, 6
Steam, effects of, 27, 34, 66
Stone Age, 274
Stratified rocks, table of, 28
Striæ, glacial, 261, 266, 269
Sturgeon, 72
Subsidence, 103, 195, 272
Sun, centre of solar system, 4
Switzerland, glaciers of, 256
Syringopora, 96

TEMPERATURE of stars, 6
Tertiary or Cainozoic era, 237
Tides, see Moon
Till, see Boulder Clay
Time, see Geological time
Tinoceras, 246
Transportation, see Glaciers
Trilobites, 56, 70
Turtles, earliest known, 162, 204
Tyndall, Professor, 65; on glacier motion, 258

UNCONFORMITY, 45
Uintatherium, 246
Underclays, 113
Uniformity, theory of, 19, 131
Upheaval of mountain chains, 36, 140, 241

VENUS's flower-basket, see Euplectella
Vertebrata, earliest known, 71
Volcanic action, 27, 66
Volcanic dust, see Dust
Volcanoes of Silurian age, 67; of Old Red Sandstone, 82; of Carboniferous, 104; of Miocene, 247

WALES, old glaciers of, 269; submergence of, 272
Wallace, Mr. A. R., on extinction of mammals, 282
Water as a geological agent, 25

XIPHODON, 246
Xiphosura, see King-crabs,

ZEUGLODON, 244
Zones of Ammonities, see Ammonites

THE END

PRINTED BY EDWARD STANFORD, 26 AND 27 COCKSPUR STREET, LONDON, S.W.

00038662

Digitized with financial assistance from the
Government of Maharashtra
on 05 October, 2018